

**STATIC TENSILE AND TENSILE CREEP
TESTING OF FOUR BORON NITRIDE
COATED CERAMIC FIBERS
AT ELEVATED TEMPERATURES**



Scott L. Cogull
Donald F. Adams
Richard S. Zimmerman

1N-24
2007
P135

August 1989

FINAL REPORT

NASA-Ames Research Center
Moffett Field, California
NASA Grant No. NAG-2-470

(NASA-CR-184999) STATIC TENSILE AND TENSILE
CREEP TESTING OF FOUR BORON NITRIDE COATED
CERAMIC FIBERS AT ELEVATED TEMPERATURES
Final Report (Wyoming Univ.) 135 NCSCL 110

NPO-11307

Unclass
63/24 0222707

COMPOSITE MATERIALS RESEARCH GROUP
DEPARTMENT of MECHANICAL ENGINEERING
University of Wyoming Laramie, Wyoming 82071

REPORT UW-CMRG-R-89-123

STATIC TENSILE AND TENSILE CREEP TESTING
OF FOUR BORON NITRIDE COATED CERAMIC FIBERS
AT ELEVATED TEMPERATURES

SCOTT L. COGUILL
DONALD F. ADAMS
RICHARD S. ZIMMERMAN

AUGUST 1989

FINAL REPORT

NASA-AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA
NASA GRANT NO. NAG-2-470

COMPOSITE MATERIALS RESEARCH GROUP
MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF WYOMING
LARAMIE, WYOMING 82071

PREFACE

This technical report presents the results of a study, sponsored by NASA-Ames Research Center under Grant No. NAG 2-470, dated July 1, 1987. Dr. Demetrius A. Kourides served as the NASA-Ames Technical Monitor.

All Work was conducted by the Composite Materials Research Group (CMRG) within the Department of Mechanical Engineering at the University of Wyoming. Co-Principal Investigators were Mr. Richard S. Zimmerman, Staff Engineer, and Dr. Donald F. Adams, Professor. Making significant contributions to this program were Messrs. Hal Radloff and Steve Bartel, undergraduate students in Mechanical Engineering and members of the Composite Materials Research Group. This report was compiled by Mr. Scott L. Coguill, Staff Engineer.

Use of commercial products or names of manufacturers in this report does not constitute official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1. INTRODUCTION	1
2. SUMMARY OF RESULTS	6
3. EXPERIMENTAL RESULTS	13
3.1 Scanning Electron Microscope Observations	13
3.2 Static Tensile Test Results	14
3.3 Creep Test Results	31
4. CONCLUSIONS	35
REFERENCES	36
APPENDIX A: Individual Single Fiber Static Tensile Test Data	38
APPENDIX B: Individual Single Fiber Tensile Creep Test Data	75

SECTION 1

INTRODUCTION

Six types of uncoated ceramic fibers and four types of boron nitride coated ceramic fibers were static tensile tested at room temperature and four elevated temperatures. The boron nitride coated fibers and one of the uncoated fibers were also creep tested at four elevated temperatures. Testing was performed on single fibers separated from tows supplied by NASA-Ames. The six uncoated ceramic fibers chosen for this program were J.P. Stevens Co. Astroquartz 9288 glass fiber, Nippon Carbon, Ltd. (Dow Chemical) Nicalon NLM-102 silicon carbide fiber, and 3M Company Nextel 312, Nextel 380, Nextel 440, and Nextel 480 alumina/silica/boria fibers. The boron nitride coated fibers tested were the Nicalon NLM-102, and the Nextel 312, 440, and 480 fibers.

The complete test matrix is given in Tables 1 and 2. ASTM Standard Test Method D 3379-75 was used as the reference test procedure for all testing [1].

Each type of fiber was initially static tensile tested at gage lengths of 1, 2, and 4 inches, at room temperature, to determine the magnitude of end effects from the paper end tabs and grips. No creep testing was performed at room temperature. Each type of fiber was also initially static tensile tested at gage lengths of 8 and 10 inches, at one of the elevated test temperatures, to determine end effects for the elevated temperature static and creep testing. An end effect

Table 1

Test Matrix for Each Type of Uncoated Ceramic Fiber

Fiber Type	Test Method	Test Temperature (°C)	Gage Length (inches)	No. of Replicates
Astroquartz 9288	Static	25	1	10
			2	10
			4	10
		500	8	5
			10	5
		600	8	5
		700	8	5
		800	8	5
Nicalon NML-102	Static	25	1	10
			2	10
			4	10
		1000	8	5
			10	5
		1100	8	5
		1200	8	5
		1300	8	5
Nextel 312	Static	25	1	10
			2	10
			4	10
		400	8	5
		500	8	5
			10	5
		600	8	5
		700	8	5
Nextel 380	Static	25	1	10
			2	10
			4	10
		600	8	5
			10	5
		700	8	5
		800	8	5
		900	8	5

Table 1 (cont.)

Fiber Type	Test Method	Test Temperature (°C)	Gage Length (inches)	No. of Replicates
Nextel 440	Static	25	1	10
			2	10
			4	10
		500	8	5
			10	5
		600	8	5
			10	5
		700	8	5
			10	5
		800	8	5
	Creep	500	8	3
		600	8	3
		700	8	3
		800	8	3
Nextel 480	Static	25	1	10
			2	10
			4	10
		900	8	5
		1000	8	5
			10	5
		1100	8	5
		1200	8	5

Table 2

Test Matrix For the Four Boron Nitride Coated Ceramic Fibers

Test Method	Test Temperature (°C)	Gage Length (inches)	No. of Replicates
Static	25	1	10
		2	10
		4	10
	500	8	10
		10	10
	600	8	10
		10	10
	700	8	10
		10	10
	800	8	10
		10	10
Creep	500	8	3
	600	8	3
	700	8	3
	800	8	3

correction was found to be unnecessary for the elevated temperature testing. All subsequent elevated temperature testing, both static and creep, was thus performed utilizing only 8 inch long specimens.

As will be noted in Tables 1 and 2, the creep test temperatures used were slightly lower than the static tensile test temperatures. This was to compensate for the much longer time the fibers being creep tested spent at the elevated temperatures. The high temperatures for long durations were causing severe degradation of the fibers. Static testing nominally subjected each fiber to the elevated temperature for only 1 to 3 minutes. The creep test duration was nominally four hours. Exposure in an air atmosphere at the highest temperatures for this comparatively long time was found to degrade the ceramic fibers too much. Thus, lower test temperatures for creep were utilized to ensure properties could be measured.

A summary of all of the test results is presented in the next section. Specimen fabrication techniques and descriptions of the test apparatus used can be found in Reference [2], which is the previous report on single ceramic fiber testing. Test methods and detailed experimental results are given in Section 3. Appendix A contains the individual single fiber static tensile test results, while Appendix B contains individual tensile creep test results.

SECTION 2

SUMMARY OF RESULTS

Single fiber static tensile testing at various elevated temperatures was performed on all ten uncoated and boron nitride coated types of ceramic fibers supplied by NASA-Ames. The boron nitride coated ceramic fibers and one of the uncoated fibers were subject to tensile creep testing at various elevated temperatures. All uncoated fibers were supplied as untwisted rovings, both sized and unsized. The single fibers used for all testing were carefully separated by hand from the unsized rovings. It was found that sized fibers could not be utilized since the fibers adhered to each other to such a great degree that individual fibers could not be extracted from the fiber bundles without damaging them.

Static testing was performed on each of the uncoated and coated ceramic fibers at room temperature and four elevated temperatures, to provide baseline data for each fiber type. Because of the differences in temperature sensitivity of the different types of fibers, each type was tested at a slightly different set of elevated temperatures, selected to be consistent with the sensitivity of that particular fiber. The creep testing was only performed on the four boron nitride coated ceramic fibers and on the uncoated Nextel 440 ceramic fiber. Additional creep data on uncoated fibers is presented in Reference [2]. All creep tests were to be conducted at a stress level equal to at least 40 percent of the corresponding static tensile strength measured at that

test temperature. This was the highest stress level the boron nitride coated fibers could withstand. Higher stresses caused the fibers to fail while loading the creep fixture. Actual creep stress levels varied for the four boron nitride coated fiber types due to limits imposed by the strain measurement instrumentation and widely varying fiber sizes encountered. The strain measurement limit was 2 percent, dictated by the small LVDTs used to measure fiber displacements and the long specimen gage lengths. The uncoated Nextel 440, the boron nitride Nextel 312 and the boron nitride Nextel 480 fibers were creep tested nominally at 40 percent of their ultimate stress levels. The boron nitride Nicalon NLM-102 and the boron nitride Nextel 440 fibers were creep tested nominally at 50 percent of their ultimate stresses. These stress levels kept strain measurements within the above mentioned limits for all fibers. All creep testing was performed at the same test temperatures as the static tensile testing.

Data are presented in graphical form in this summary, to provide the reader with relative magnitudes and temperature capabilities for the different types of coated ceramic fibers. As will be noted, the test temperatures were quite different. Thus, comparisons of fiber properties should be made carefully, to avoid improper conclusions as to the capability of each fiber at elevated temperature. For each of the types of fibers, testing was performed up to the highest temperature that still yielded reasonable mechanical properties. It was found that properties fell dramatically above the highest temperatures reported here.

Average static tensile properties for the boron nitride coated ceramic fibers are shown in Figures 1 through 3, while average tensile

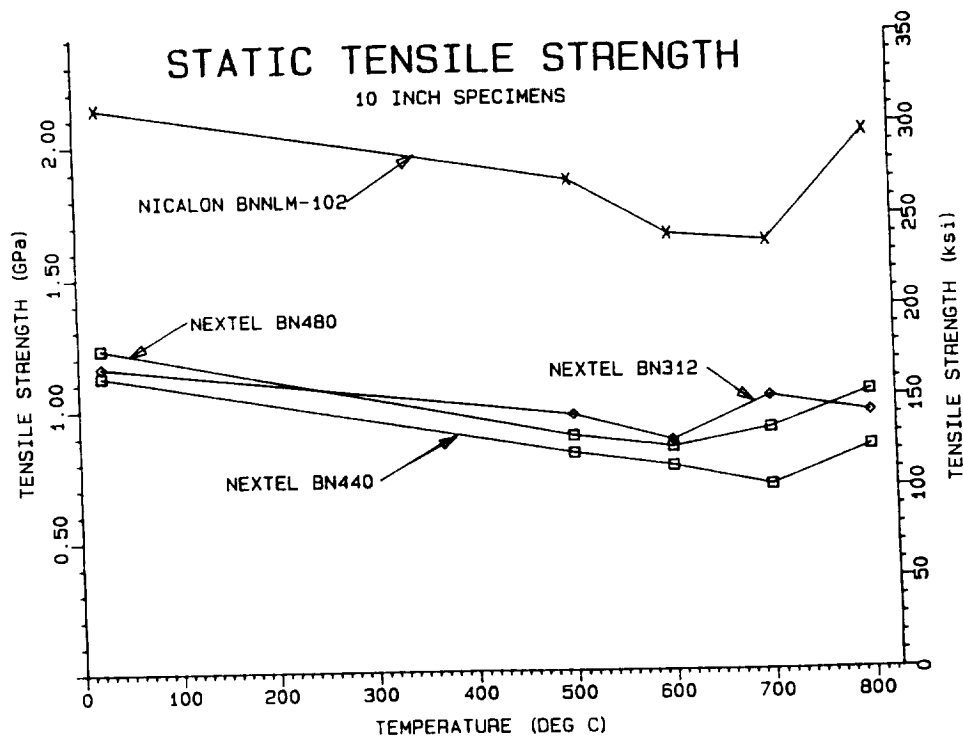
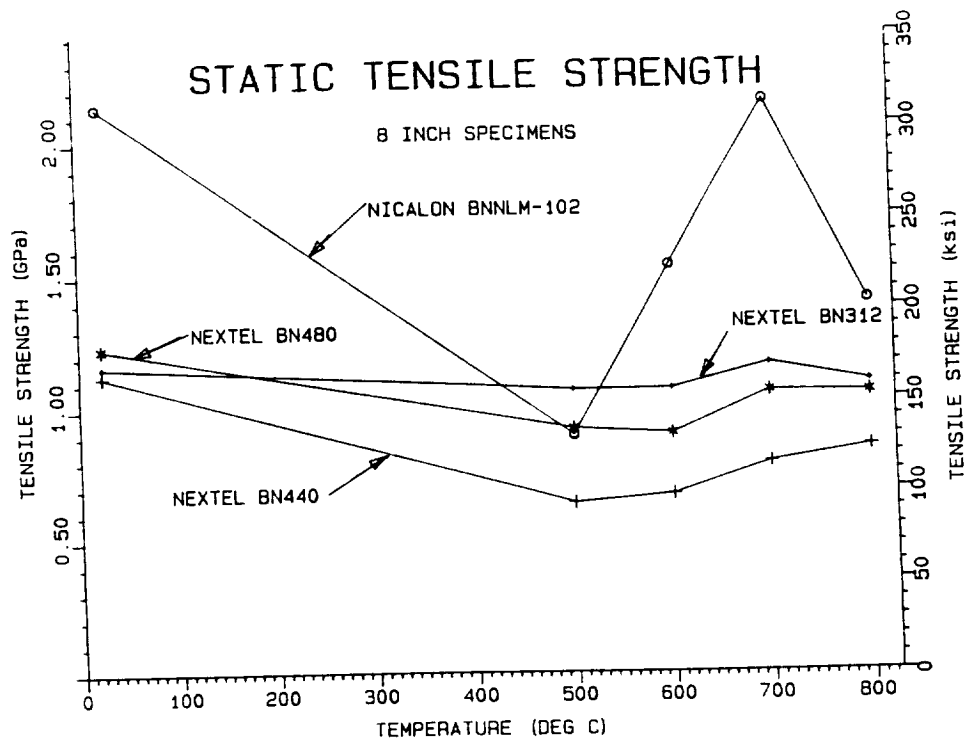


Figure 1. Average Static Tensile Strengths of Single Boron Nitride Coated Ceramic Fibers at Two Specimen Lengths.

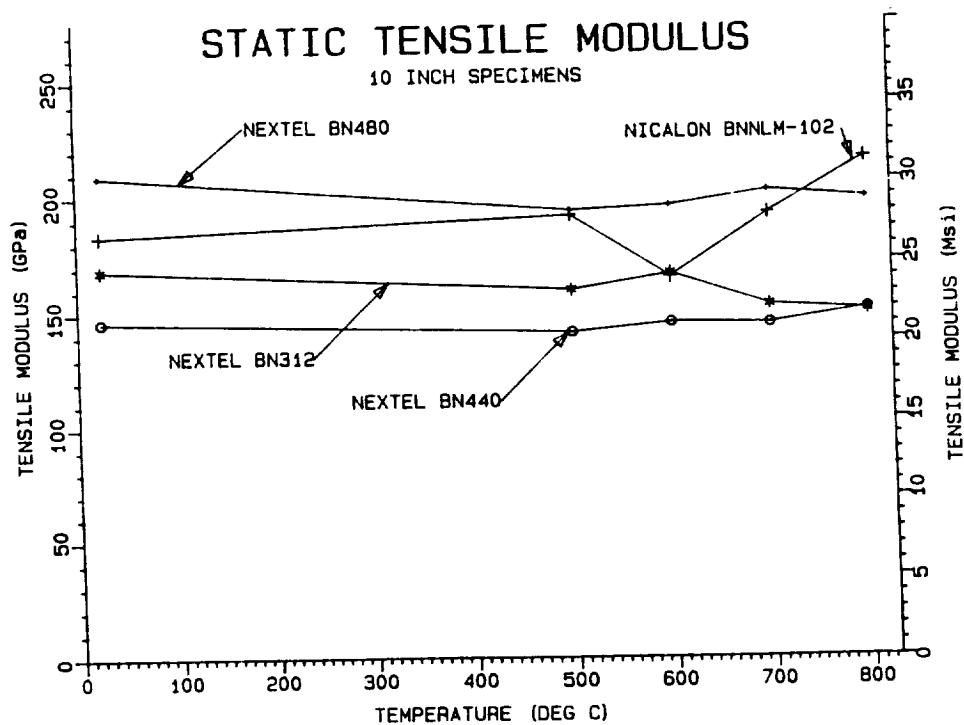
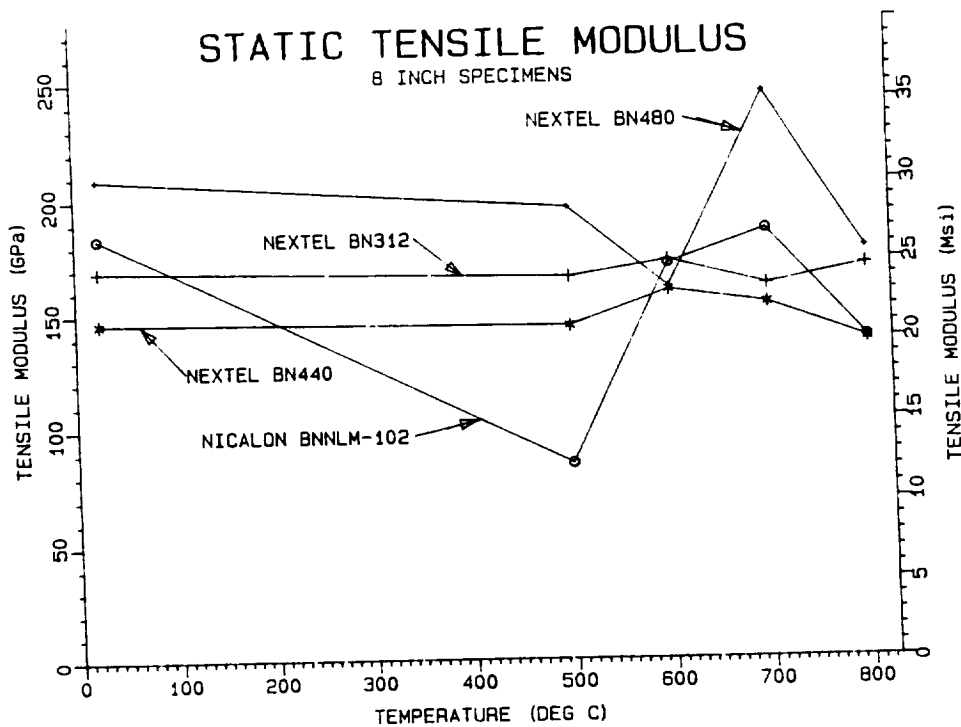


Figure 2. Average Static Tensile Moduli of Single Boron Nitride Coated Ceramic Fibers at two Specimen Lengths.

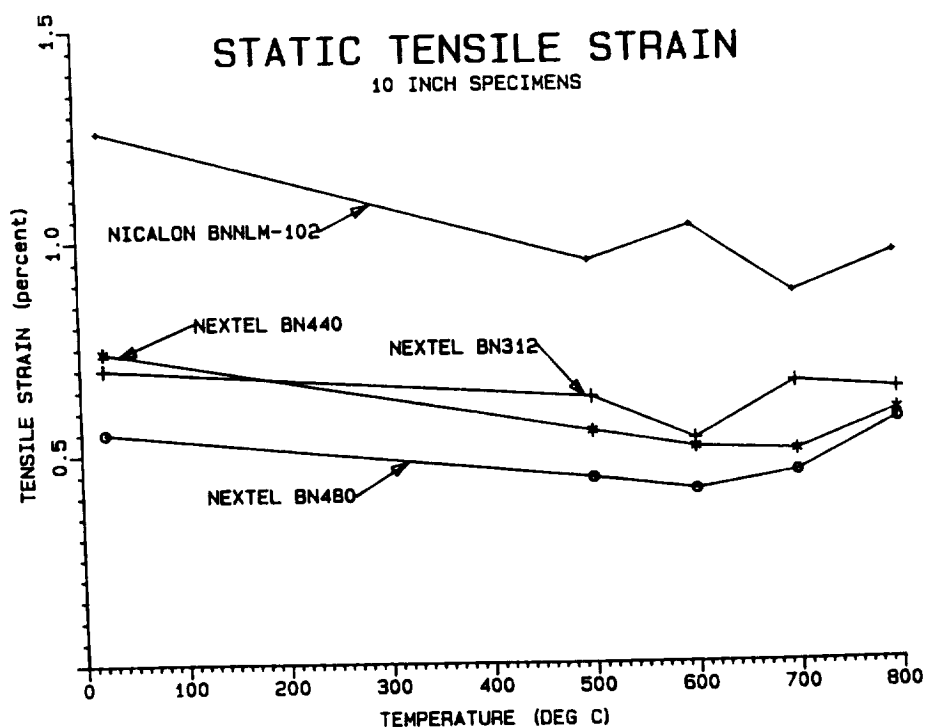
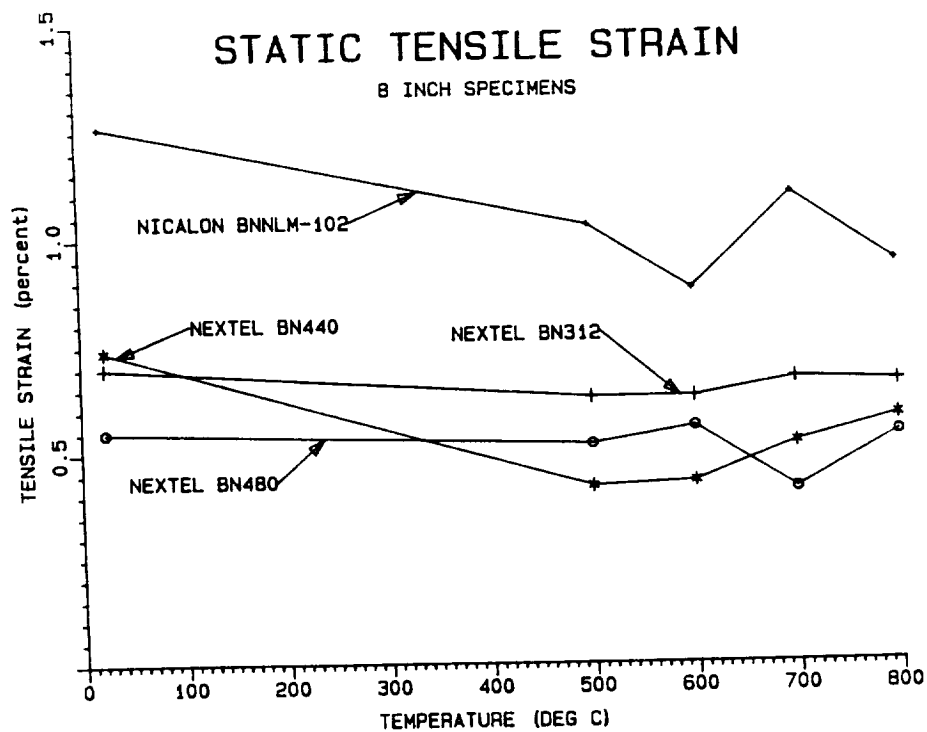


Figure 3. Average Static Tensile Strains of Single Boron Nitride Coated Ceramic Fibers at Two Specimen Lengths.

creep rates are shown in Figure 4. The average data presented here in graphical form are presented again in tabular form in Section 3. Individual test specimen results are presented in Appendices A and B.

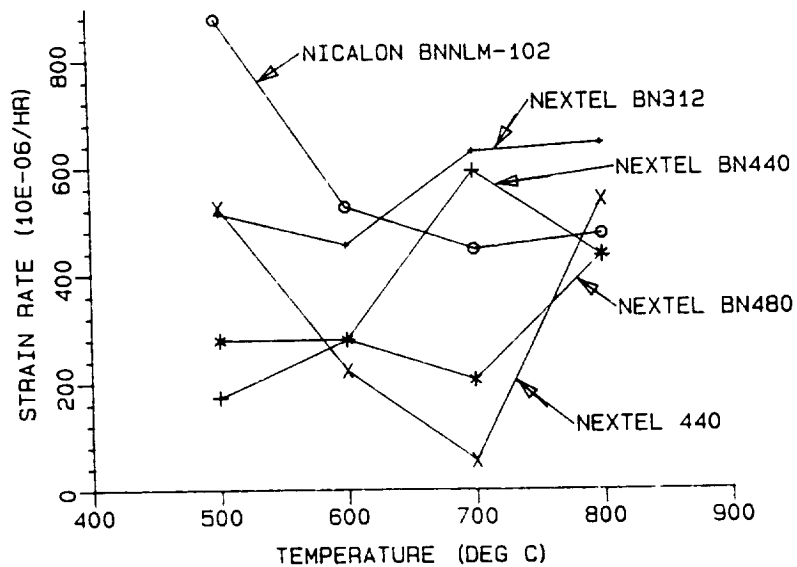
Some experimental work had been performed previously by other researchers using fiber tows to determine similar properties for the six uncoated materials tested in this study [3-5]. Considerable effort was expended here in developing the required test apparatus for performing single fiber static tensile and tensile creep tests. Single fiber testing requires a great deal of patience and care in specimen preparation due to the fragile nature of the fibers and the affinity of the fibers for other fibers in the tow. Careful handling is also critical once specimens are fabricated, to ensure the fiber specimens are not damaged prior to testing.

A scanning electron microscope (SEM) was used to photograph groups of fibers, to provide an overall indication of the fiber diameters and shapes, and their variations.

The test specimen configuration and test apparatus used for static tensile and tensile creep are described in detail in Reference [2].

CREEP STRAIN RATE

(SLOPE TAKEN BETWEEN 1/2 HOUR AND 1 HOUR OF TEST)



CREEP STRAIN RATE

(SLOPE TAKEN BETWEEN 1/2 HOUR AND END OF TEST)

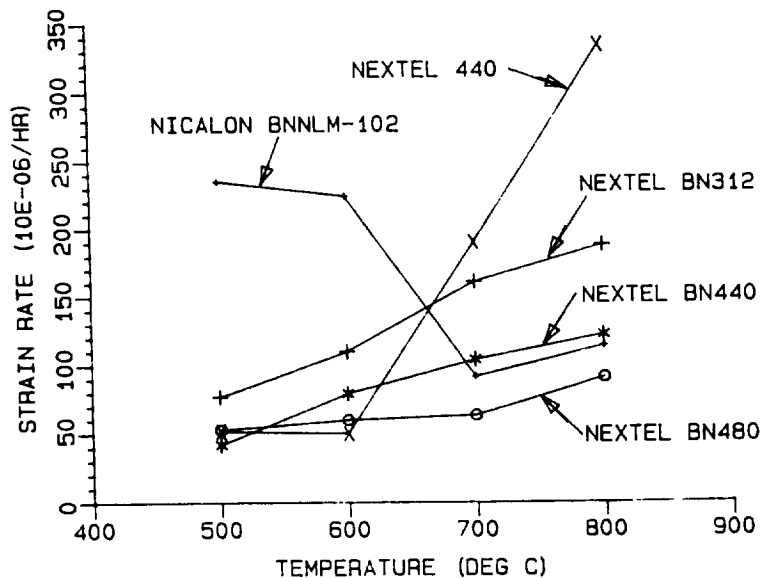


Figure 4. Average Tensile Creep Strain Rates of Single Boron Nitride Coated Ceramic Fibers.

SECTION 3

EXPERIMENTAL RESULTS

The six uncoated fibers tested were J.P. Stevens Astroquartz 9288 glass fiber, Nippon Carbon, LTD. (Dow Corning) Nicalon NLM-102 silicon carbide fiber, and 3M Company Nextel 312, Nextel 380, Nextel 440, and Nextel 480 alumina/silica/boria fibers. The four boron nitride coated fibers were Nicalon NLM-102, Nextel 312, Nextel 440, and Nextel 480. The six uncoated ceramic fibers were static tensile tested at room temperature and four elevated temperatures. The four coated fibers, as well as the uncoated Nextel 440, were tensile creep tested at the four elevated temperatures listed in Table 2 of Section 1. No creep testing was performed at room temperature.

Young's modulus, tensile strength, tensile strain, and creep strain, were the mechanical properties determined at each test temperature for the six types of fibers.

Average test results are presented here while individual test data are given in Appendix A.

3.1 Scanning Electron Microscope Observations

All fiber types were photographed using a scanning electron microscope (SEM) to determine their typical shapes and diameters. This determination was very important since it was necessary to calculate the fiber cross-sectional areas. For the present study, all data were reduced using the average cross-sectional area values determined from

the SEM photographs. Due to fiber to fiber size variations, this introduced some scatter in the data, particularly for the types of fibers that exhibited greater geometric variations. The fiber dimensions for all the uncoated fibers, except Nextel 440, were taken from Reference [2].

Reference [9] contains an equation, repeated below as Eq. (1), used by 3M Company to calculate the approximately elliptical area of the Nextel fibers.

$$\text{Area} = (\text{major dia.}) \times (\text{minor dia.}) \times (0.87) \quad (1)$$

The equation for a true ellipse is:

$$\text{Area} = (\text{major dia.}) \times (\text{minor dia.}) \times (\pi/4) \quad (2)$$

Eq. (1) was used to make the area calculations per the recommendations of the manufacturer of the Nextel fibers, the 3M Company.

Figure 5 is a SEM photograph of a group of Nextel 440 fibers. Figures 6 through 9 are SEM photographs of groups of boron nitride coated Nicalon NLM-120, Nextel 312, Nextel 440, and Nextel 480. The coating of boron nitride did not change the general shape of the fibers.

Comparisons of fiber sizes and shapes obtained from the SEM study are given in Table 3.

3.2 Static Tensile Test Results

Table 4 presents average static tensile strengths, moduli, and strains to failure for the six types of uncoated ceramic fibers. The



Figure 5. Scanning Electron Microscope Photograph of a Group of Nextel 440 Fibers.

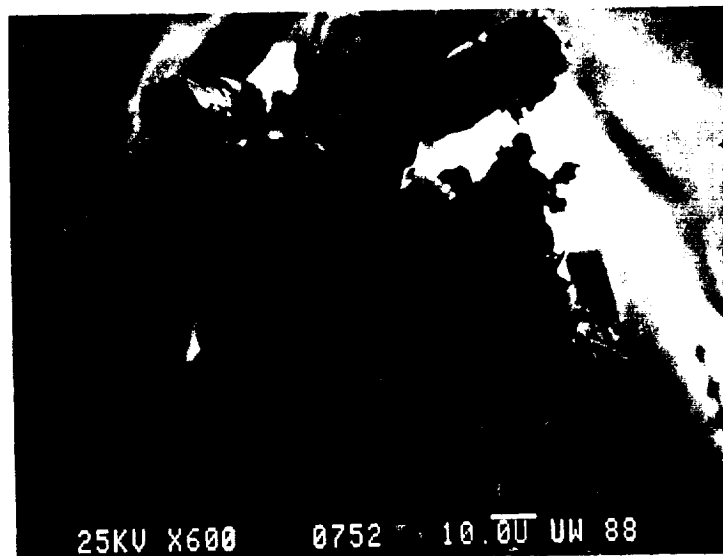


Figure 6. Scanning Electron Microscope Photograph of a Group of Coated Nicalon NLM-102 Fibers.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



Figure 7. Scanning Electron Microscope Photograph of a Group of Coated Nextel 312 Fibers.

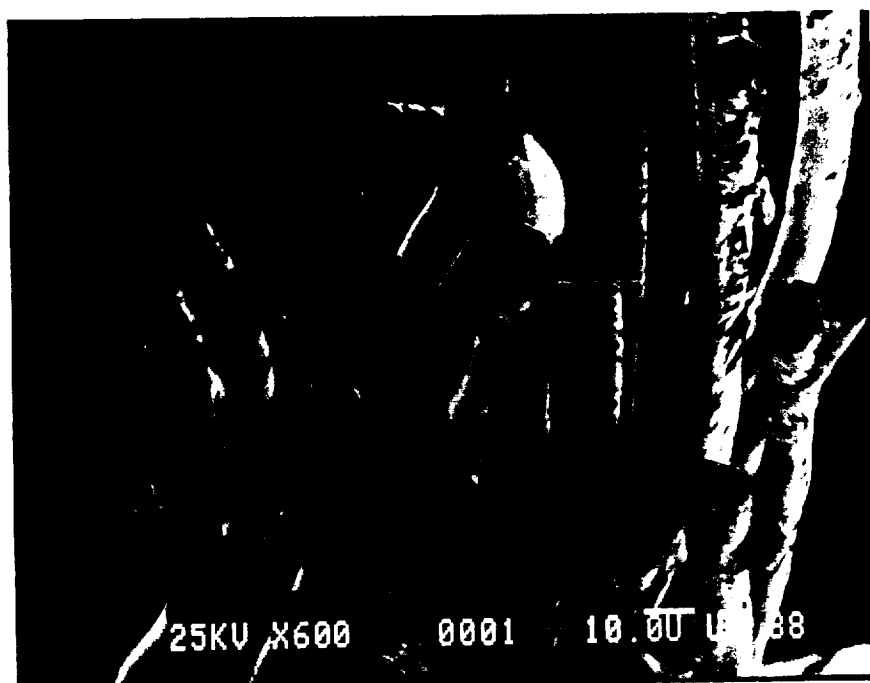


Figure 8. Scanning Electron Microscope Photograph of a Group of Coated Nextel 440 Fibers.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



Figure 9. Scanning Electron Microscope Photograph of a Group of Coated Nextel 480 Fibers.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Table 3

Average Fiber Dimensions as Measured from
Scanning Electron Microscope Photographs

Fiber Type	Fiber Shape	Diameter (μm)	Area (μm^2)
Astroquartz 9288	round	8.75	60.1
Nicalon NLM-102	round	13.8	149.6
Nextel 312	ellip.	7.8 by 12.5	84.8
Nextel 380	ellip.	8.2 by 13.2	94.2
Nextel 480	ellip.	7.2 by 11.5	72.0
Nextel 440	ellip.	7.8 by 13.0	88.2
Coated Nicalon NLM-102	round	14.9	174.4
Coated Nextel 312	ellip.	7.8 by 13.0	88.2
Coated Nextel 440	ellip.	9.8 by 13.5	115.1
Coated Nextel 480	ellip.	9.8 by 12.5	106.6

Note: The values for the first five fibers listed are from Reference [2].
Area of elliptical shapes = (major dia.) x (minor dia.) x (0.87) [9].

six types of fibers were tested at the highest temperatures that still gave reasonable mechanical properties for that type of fiber. Each fiber was tested at slightly different temperatures, as indicated in Tables 1 and 4. The maximum reasonable test temperatures were all determined in Reference [2], except the test temperatures for Nextel 440, which were evaluated during this study.

Fiber strength was the major parameter used in establishing the highest temperatures the fibers were to be tested at. It will be noted in Table 4 that the fiber modulus values did not show as much of a drop as the fiber strengths. All of the fibers suffered losses in tensile strength at the higher test temperatures well before they exhibited much loss of stiffness.

Table 4 also presents average static tensile strains to failure for the six types of ceramic fibers tested in this program. As the table indicates, the average ultimate strains for all of the fibers were less than two percent, and did not vary significantly as a function of test temperature.

Table 5 presents the average static tensile test results for the four boron nitride coated ceramic fibers. The elevated test temperatures were the same as those used in the creep tests.

Figures 10 through 16 portray the effect of the boron nitride coating on static tensile test results. Only test results on coated and uncoated fibers at the same test temperature were compared. This only allowed the direct comparison of two fiber types, coated and uncoated Nextel 312 and 440.

As the tables and figures indicate, the boron nitride coating improved the static tensile performance of the Nextel 312 fiber, but

Table 4

Average Static Tensile Data for Single Uncoated Fibers

Fiber Type	Test Temp. (°C)	Gage Length (in.)	Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
			(GPa)	(ksi)	(GPa)	(Msi)	
Astroquartz 9288	23	1	0.81	118	72	10.5	1.22
		2	0.78	112	73	10.6	1.10
		4	0.70	101	79	11.4	0.85
	500	8	1.19	146	80	11.6	1.28
		10	1.53	222	84	12.2	1.69
	600	8	1.13	164	71	10.3	1.55
	700	8	1.02	148	73	10.6	1.39
	800	8	0.79	115	70	10.1	1.28
Nicalon NLM-102	23	1	2.32	336	223	32.4	1.08
		2	2.88	417	211	30.5	1.32
		4	2.38	345	272	39.4	0.95
	1000	8	1.83	265	250	36.3	0.75
		10	1.51	219	212	30.8	0.70
	1100	8	1.91	276	227	33.0	0.85
	1200	8	1.56	226	169	24.5	1.02
	1300	8	1.28	185	164	23.7	0.80
Nextel 312	23	1	1.28	186	106	15.4	1.25
		2	1.04	151	113	16.4	0.97
		4	0.74	107	125	18.1	0.65
	400	8	1.09	158	154	22.4	0.70
	500	8	0.92	134	142	20.6	0.67
		10	0.97	140	140	20.4	0.64
	600	8	1.15	166	161	23.4	0.68
	700	8	0.75	109	110	16.0	1.14
Nextel 380	23	1	1.50	217	134	19.4	1.22
		2	1.39	202	149	21.6	0.92
		4	1.10	159	135	19.6	0.86
	600	8	1.40	204	160	23.2	0.81
		10	1.36	198	159	23.1	0.86
	700	8	1.34	194	141	20.5	0.90
	800	8	0.86	124	130	18.8	0.77
	900	8	0.90	130	127	18.4	0.74

Table 4 (Continued)

Average Static Tensile Data for Single Uncoated Fibers

Fiber Type	Test Temp. (°C)	Gage Length (in.)	Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
			(GPa)	(ksi)	(GPa)	(Msi)	
Nextel 480	23	1	2.73	396	208	30.1	1.32
		2	1.92	278	226	32.8	0.87
		4	2.03	295	227	32.9	0.86
	23	1	2.52	365	234	33.9	1.07
		2	2.42	350	245	35.4	0.93
		4	1.72	249	282	40.8	0.62
	900	8	1.73	251	233	33.7	0.73
	1000	8	1.74	252	240	34.8	0.69
		10	1.21	175	236	34.2	0.50
	1100	8	0.45	65	177	25.6	0.24
	1200	8	0.45	66	216	31.4	0.20
Nextel 440	23	1	1.79	260	181	26.2	1.00
		2	1.48	215	186	26.9	0.75
		4	1.91	277	191	27.6	1.00
	500	8	1.50	217	196	28.3	0.73
		10	1.10	160	184	26.6	0.61
	600	8	0.75	108	198	28.7	0.54
		10	1.25	182	191	27.6	0.75
	700	8	1.56	226	181	26.3	0.84
		10	1.32	192	189	27.4	0.75
	800	8	1.36	197	178	25.9	0.80
		10	1.55	224	204	29.5	0.74

Table 5

Average Static Tensile Data for Single
Boron Nitride Coated Fibers

Fiber Type	Test Temp. (°C)	Gage Length (in.)	Tensile Strength		Tensile Strength		Ultimate Strain (percent)
			(GPa)	(ksi)	(GPa)	(Msi)	
Coated Nextel 312	23	1	1.35	196	161	23.3	0.79
		2	1.14	165	169	24.5	0.66
		4	1.17	169	169	24.5	0.70
	500	8	1.07	156	166	24.0	0.63
		10	0.97	141	160	23.2	0.63
	600	8	1.08	156	173	25.0	0.63
		10	0.88	127	167	24.2	0.53
	700	8	1.17	169	161	23.4	0.67
		10	1.04	151	154	22.2	0.66
	800	8	1.10	159	170	24.6	0.66
		10	0.98	141	151	21.8	0.64
Coated Nextel 440	23	1	1.17	170	135	19.5	0.63
		2	1.24	180	143	20.7	0.87
		4	1.13	164	146	21.2	0.74
	500	8	0.64	93	144	20.9	0.42
		10	0.83	120	142	20.5	0.55
	600	8	0.67	98	159	23.1	0.43
		10	0.78	113	146	21.1	0.51
	700	8	0.79	115	153	22.2	0.52
		10	0.70	102	145	21.0	0.50
	800	8	0.85	123	137	19.9	0.58
		10	0.85	123	151	21.9	0.59
Coated Nextel 480	23	1	1.25	181	176	25.5	0.61
		2	0.99	144	160	23.2	0.62
		4	1.24	179	209	30.3	0.55
	500	8	0.92	134	197	28.4	0.52
		10	0.83	121	194	28.1	0.44
	600	8	0.91	131	161	23.3	0.56
		10	0.85	123	196	28.4	0.41
	700	8	1.06	154	244	35.4	0.41
		10	0.92	133	202	29.3	0.45
	800	8	1.04	151	177	25.7	0.54
		10	1.06	153	199	28.8	0.57

Table 5 (Continued)

Average Static Tensile Data for Single
Boron Nitride Coated Fibers

Fiber Type	Test Temp. (°C)	Gage Length (in.)	Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
			(GPa)	(ksi)	(GPa)	(Msi)	
Coated Nicalon NLM-102	23	1	1.98	287	128	18.6	1.52
		2	2.93	424	210	30.4	1.41
		4	2.15	311	183	26.6	1.26
	500	8	0.90	130	85	12.3	1.03
		10	1.87	270	192	27.8	0.95
	600	8	1.54	223	171	24.8	0.88
		10	1.66	241	166	24.0	1.03
	700	8	2.16	313	186	26.9	1.10
		10	1.63	236	193	27.9	0.87
	800	8	1.40	203	138	20.0	0.94
		10	2.04	296	216	31.3	0.96

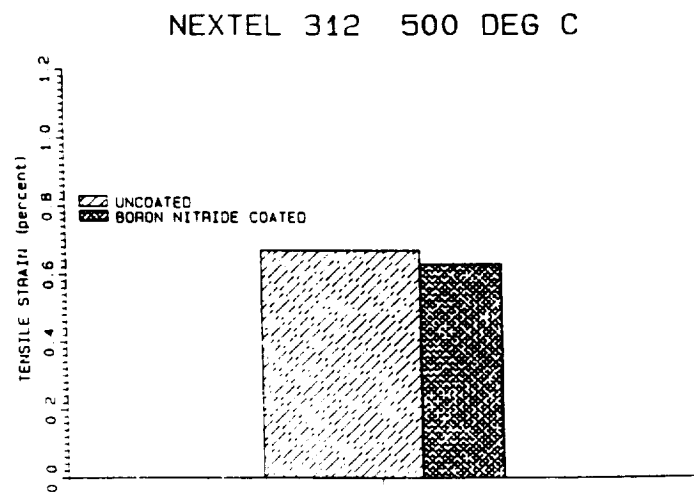
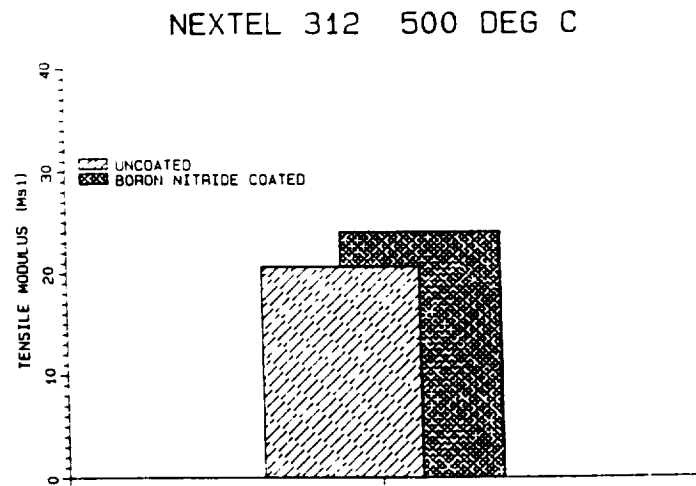
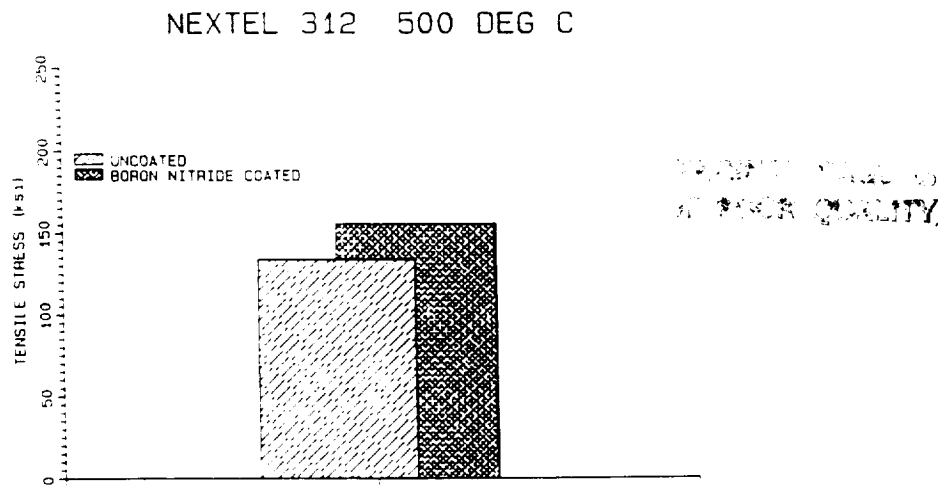
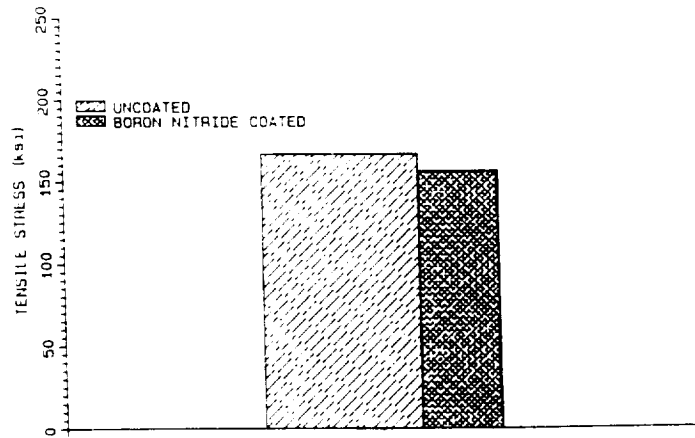
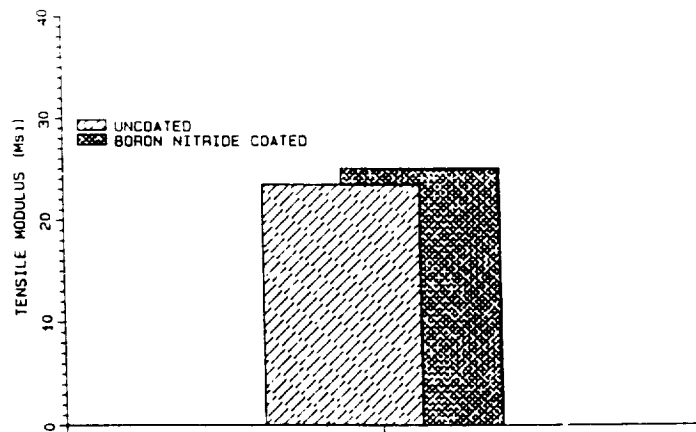


Figure 10. Comparison of Coated and Uncoated Nextel 312 Tensile Properties at 500°C.

NEXTEL 312 600 DEG C



NEXTEL 312 600 DEG C



NEXTEL 312 600 DEG C

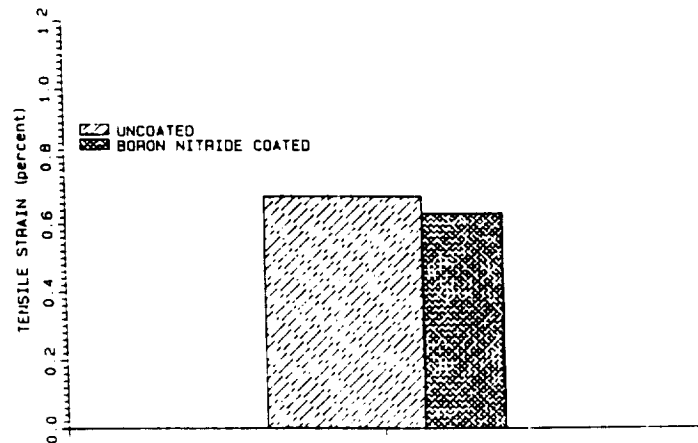
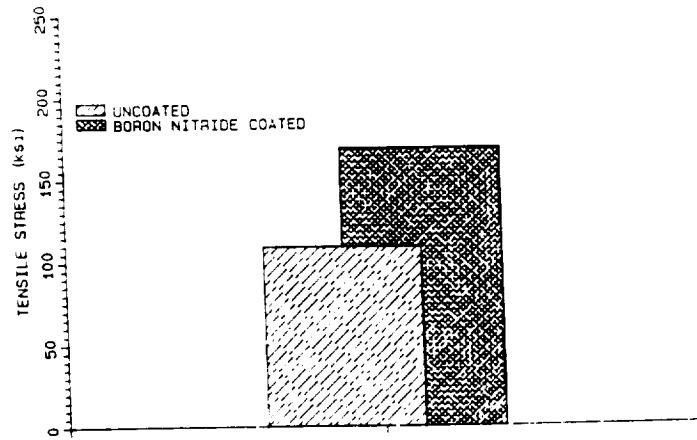
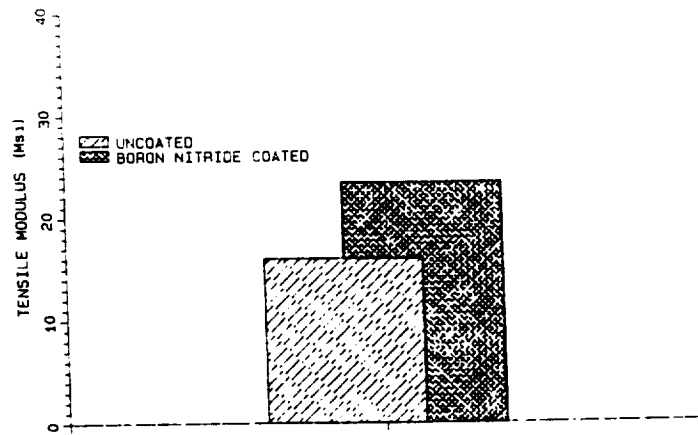


Figure 11. Comparison of Coated and Uncoated Nextel 312 Tensile Properties at 600°C.

NEXTEL 312 700 DEG C



NEXTEL 312 700 DEG C



NEXTEL 312 700 DEG C

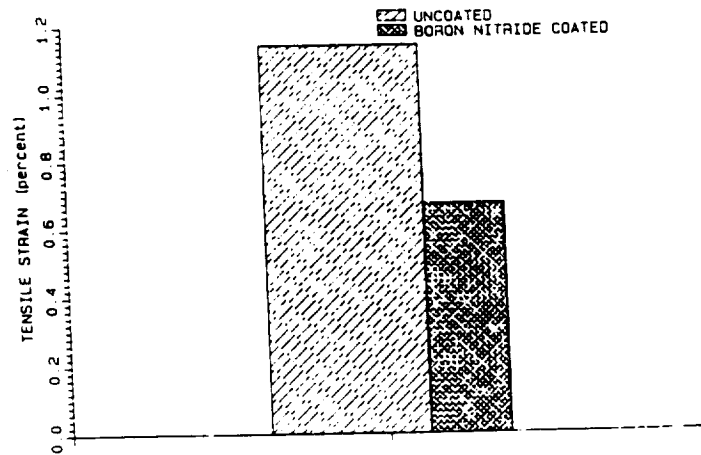


Figure 12. Comparison of Coated and Uncoated Nextel 312 Tensile Properties at 700°C.

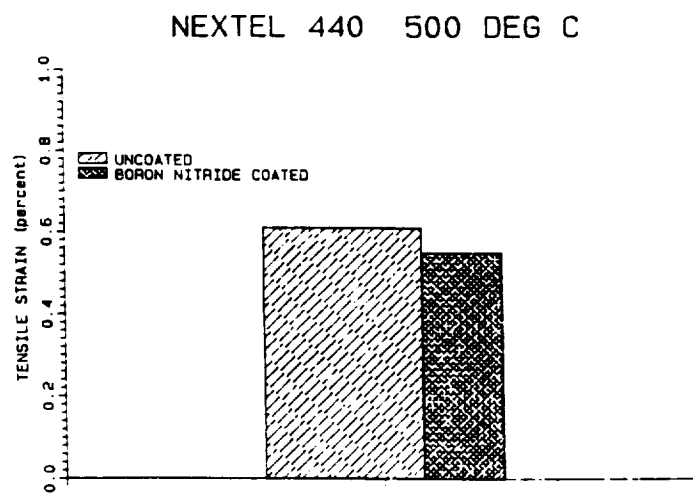
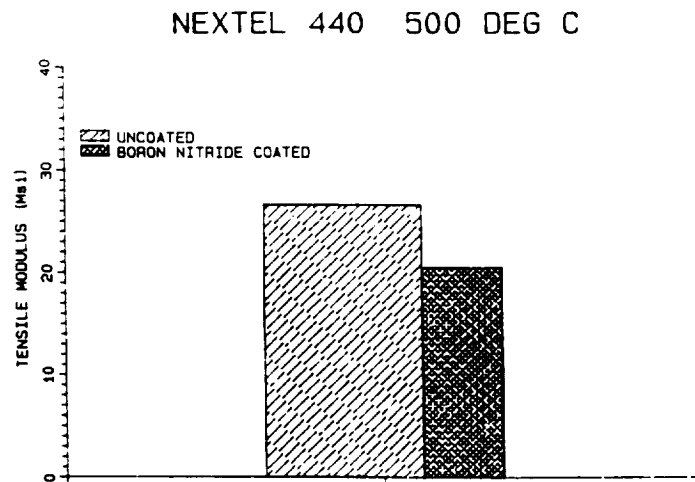
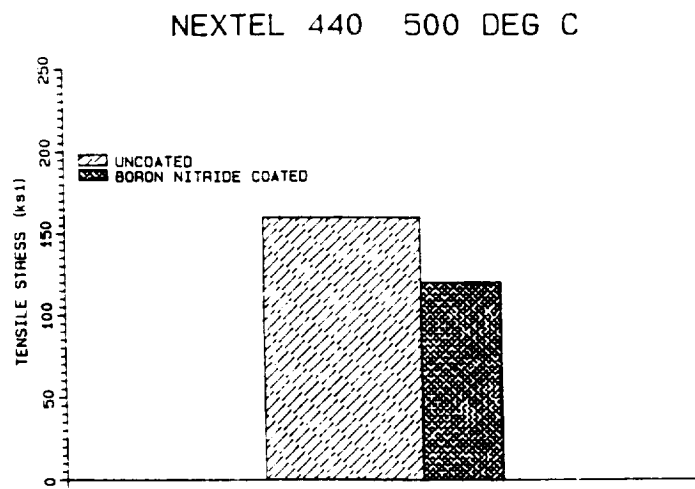


Figure 13. Comparison of Coated and Uncoated Nextel 440 Tensile Properties at 500°C.

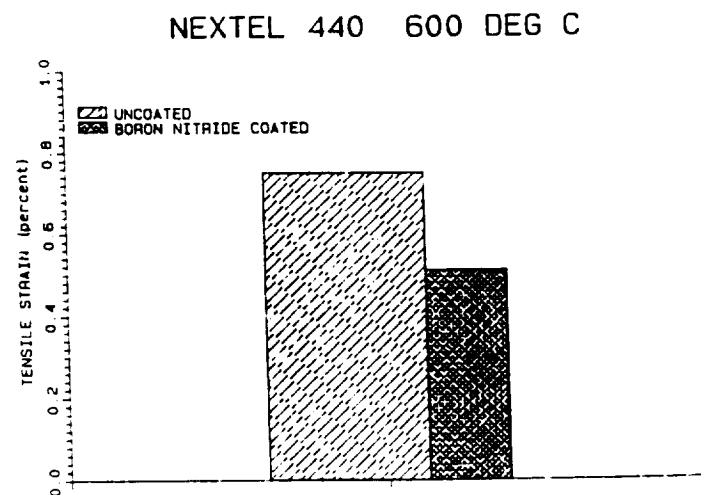
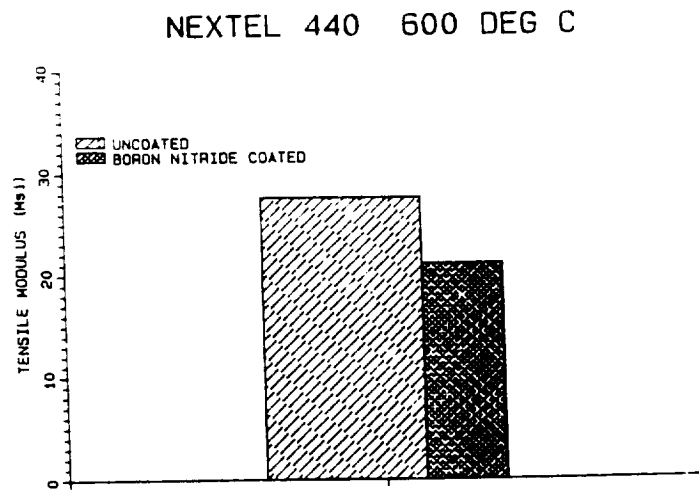
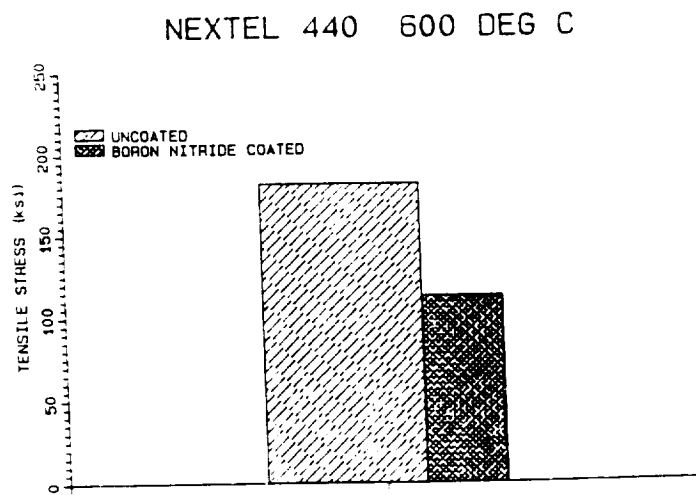


Figure 14. Comparison of Coated and Uncoated Nextel 440 Tensile Properties at 600°C.

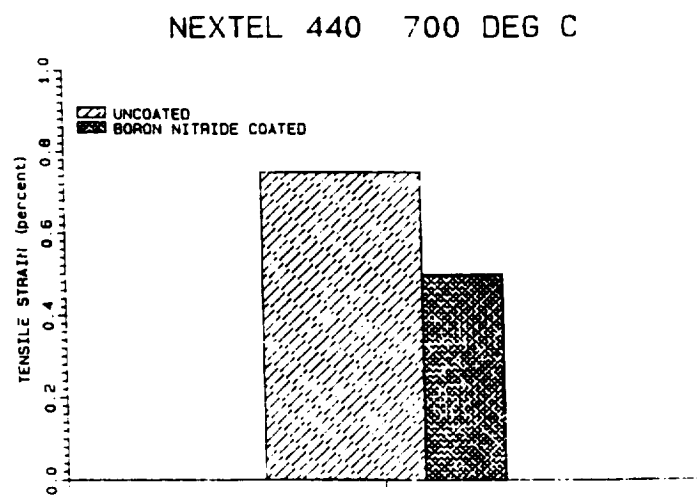
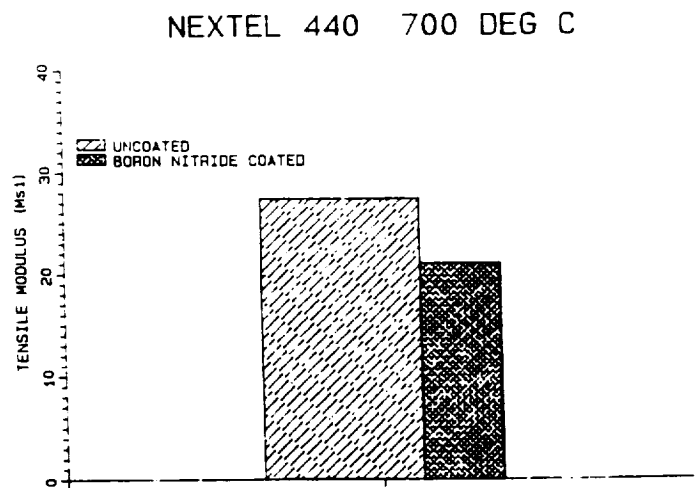
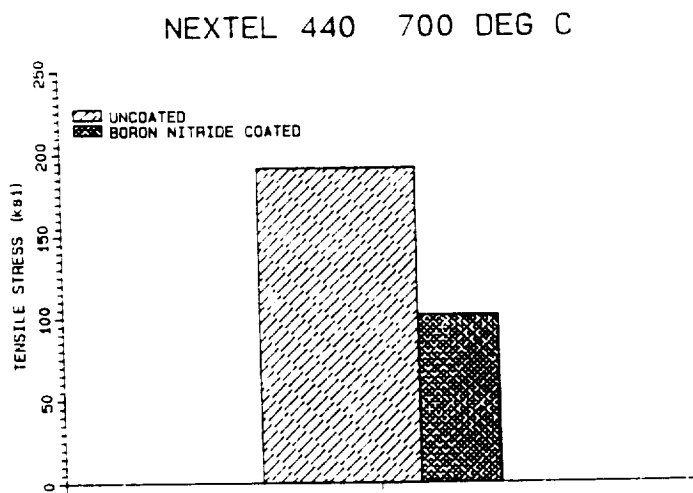


Figure 15. Comparison of Coated and Uncoated Nextel 440 Tensile Properties at 700°C.

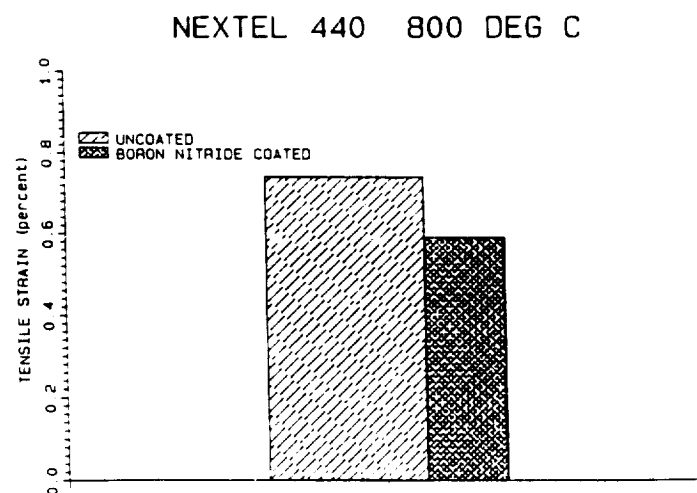
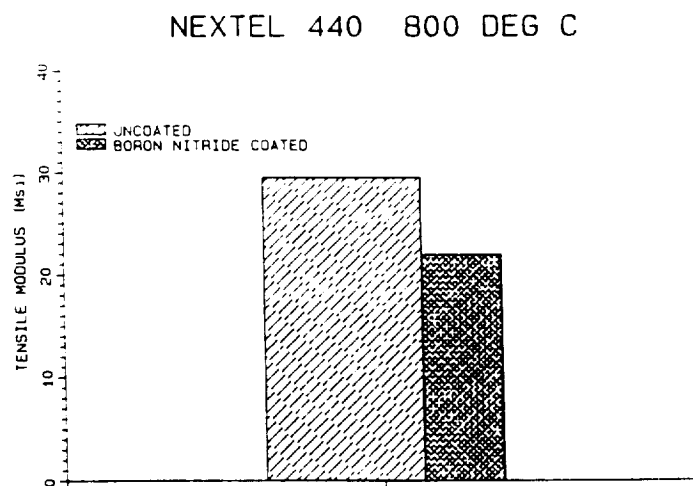
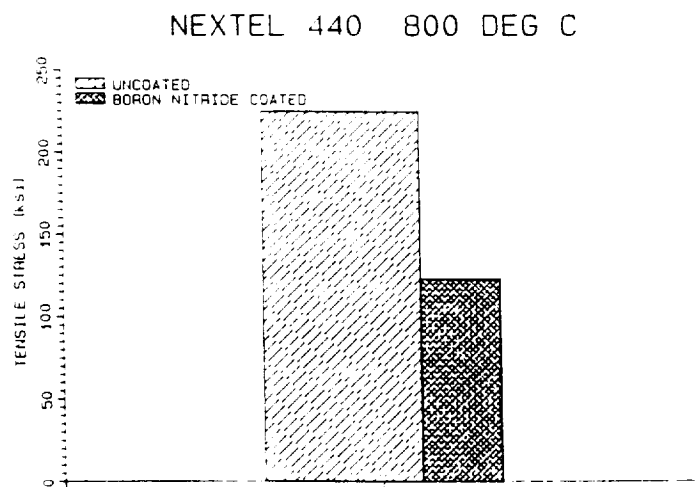


Figure 16. Comparison of Coated and Uncoated Nextel 440 Tensile Properties at 800°C.

appeared to lower static tensile results for the Nextel 440 fiber. A lack of improvement by the coating was also indicated by the strength trends when comparing the other coated to uncoated fibers.

3.3 Creep Test Results

Table 6 presents the average creep rates calculated after $\frac{1}{2}$ hour at each of the four elevated test temperatures each type of fiber was tested at. It will be noted that the four elevated test temperatures used for the creep testing of the five types of ceramic fibers were the same as those used for the static tensile testing of each type of fiber. Creep testing was performed only on the boron nitride coated fibers and on the Nextel 440 ceramic fiber.

A typical strain versus time curve generated from the creep testing is presented in Figure 17, to illustrate the creep response observed for the ceramic fibers tested in the present study. The remainder of the creep curves are included in Appendix B. All fibers were loaded to a slightly different percent of the static ultimate stresses measured at the four elevated test temperatures given in Table 5. The creep stress levels used here were somewhat lower than those of Reference [2]. The stress levels used were the highest the fibers could withstand. The boron nitride coating weakened the fibers. Lower creep stresses were necessary to prevent premature fiber failure when loading the fiber into the creep fixture. Each creep test was terminated after four hours; recovery strain was not monitored.

The creep rates presented here (Table 6) were calculated using two discrete time intervals. Creep rates were calculated using a linear regression technique to calculate the slopes between the two time

Table 6

Average Creep Rates for Five Types of Ceramic Fibers Tested

Fiber Type	Test Temperature (°C)	Applied Stress* (ksi)	Strain Rate from $\frac{1}{2}$ Hour to 1 Hour (10^{-6} /hour)	Strain Rate from $\frac{1}{2}$ Hour to End of Test** (10^{-6} /hour)
<u>Uncoated Nextel 440</u>				
	500	80	524	52
	600		223	50
	700		54	190
	800		539	334
<u>Boron Nitride Nextel 312</u>				
	500	64	513	77
	600		454	110
	700		630	161
	800		646	188
<u>Boron Nitride Nextel 440</u>				
	500	60	173	42
	600		280	80
	700		593	104
	800		434	122
<u>Boron Nitride Nextel 480</u>				
	500	60	279	53
	600		280	60
	700		206	63
	800		437	91
<u>Boron Nitride Nicolon NLM-102</u>				
	500	136	878	235
	600		525	224
	700		447	92
	800		475	114

* Creep stresses were at least 40 percent of ultimate stress at highest test temperature.

**Typically four hours.

DT5801.CRP

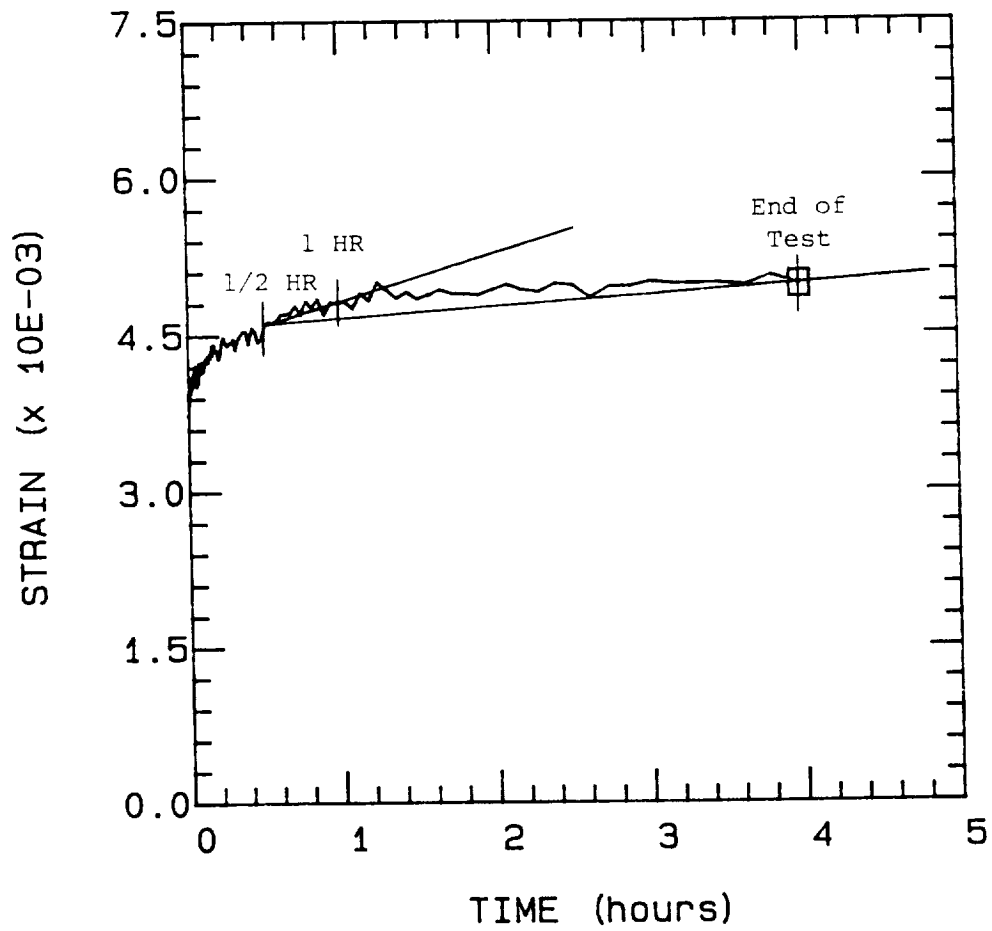


Figure 17. Typical Strain vs. Time Creep Plot Showing Two Creep Strain Rates.

intervals. One time interval was between $\frac{1}{2}$ hour and 1 hour elapsed time at the beginning of each creep test. The second interval was between $\frac{1}{2}$ hour and the end of each test, typically 3 to 4 hours total creep duration. Figure 17 illustrates the slopes calculated from the strain versus time curves. The earlier time interval yields a higher creep rate, as expected, and noted in Table 6 and Figure 17.

SECTION 4

CONCLUSIONS

The six uncoated ceramic fibers tested exhibited reasonable static mechanical properties over a wide temperature range from room temperature up to 1300°C. The results were very similar to those obtained in Reference [2]. Each fiber was tested over different temperature ranges consistent with their individual capabilities. Four of the fiber types previously tested were supplied in a boron nitride coated form. These four coated fibers exhibited different static mechanical properties than their uncoated forms. The coated fibers were tested at lower test temperatures than most of the uncoated fibers. Creep testing was performed on one of the uncoated fibers and four fiber types coated with boron nitride. Creep test temperatures were the same as those used in the static tensile tests of coated fibers.

These ceramic fibers are extremely brittle, which contributed to the data scatter seen in some of the reported data. Strength properties were most affected, with high standard deviations seen in the data. Variations in cross-sectional area of the fibers also contributed to the scatter.

The boron nitride coating only seemed to improve the performance of the Nextel 312 fiber. Testing of the other coated fibers resulted in similar or lower test values when compared to their uncoated counterparts.

REFERENCES

1. "Standard Test Method for Tensile Strength and Young's Modulus for High Modulus Single-Filament Materials," ASTM Standard Test Method D-3379-75 (Re-approved 1982), 1986 Annual Book of ASTM Standards, Section 15, American Society For Testing and Materials, Philadelphia, Pennsylvania, Volume 15.03, pp. 181-186, 1986.
2. Zimmerman, R. S. and Adams, D. F. "Static Tensile and Tensile Creep Testing of Five Ceramic Fibers at Elevated Temperatures," NASA Contractor Report 177525, April 1989.
3. Sawko, P.M., and Tran, H.K., "Strength and Flexibility Properties of Advanced Ceramic Fabrics," SAMPE Quarterly, Volume 17, No. 1, October 1985, pp. 7-13.
4. Simon, G., and Bunsell, A.R., "Mechanical and Structural Characterization of the Nicalon Silicon Carbide Fibre," Journal of Materials Science, Vol. 19, November 1984, pp. 3649-57.
5. Holtz, A.R. and Grether, M.F., "High Temperature Properties of Three Nextel Ceramic Fibers," Proceedings of the 32nd International SAMPE Symposium and Exhibition, Anaheim, California, April 1987.
6. "Astroquartz II Glass Fiber Roving," Product Bulletin No. 2100-34, J.P. Stevens and Company, Greenville, South Carolina, 1985.
7. "Astroquartz II - 350°F Epoxy Laminates," Product Bulletin, J.P. Stevens and Company, Greenville, South Carolina, October 1984.
8. "Nicalon NLM-102," Product Bulletin No. 19-073D-86, Dow Corning Corporation, Midland, Michigan, 1986.
9. Holtz, A. R., Fiber Sample Transmittal Letter, 3M Company, St. Paul, Minnesota, August 29, 1986.
10. "Nextel 312 Sewing Thread," Product Bulletin No. 98-0400-0485-9, 3M Company, St. Paul, Minnesota, 1986.
11. "Nextel 312," Product Bulletin No. K-CFPB-2, 3M Company, St. Paul, Minnesota, 1986.
12. "Nextel 440," Product Bulletin No. 98-0400-0532-8, 3M Company, St. Paul, Minnesota, 1986.
13. "Nextel 480," Product Bulletin No. 98-0400-0545-0, 3M Company, St. Paul, Minnesota, 1986.

14. Johnson, D.D., Holtz, A.R., and Grether, M.F., "Properties of Nextel 480 Fibers," Proceedings of the 11th Annual Conference on Composites and Advanced Ceramic Materials, American Ceramics Society, Cocoa Beach, Florida, January 18-23, 1987.
15. Drotning, W.D., "A Computer System for Fiber Creep Testing," Report No. SAND84-1120, Sandia Corporation, Albuquerque, New Mexico, June 1984.
16. Lubin, G., Editor, Handbook of Fiberglass and Advanced Plastics Composites, Nostrand Reinhold Company, New York, New York, 1969, p. 195.
17. Ward, I.M., Mechanical Properties of Solid Polymers, John Wiley & Sons, Ltd., Chichester, Great Britain, 1971, pp. 234-239.

Appendix A
Individual Single Fiber Static Tensile Test Data

Table A1

Individual Single Fiber Tensile Test Data for
Astroquartz 9288 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ult. Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
1" Gage Length							
ONA111	60.13	0.93	0.63	91.7*	72.0	10.4	0.89*
2			0.73	106.2	83.2	12.1*	0.92*
3			1.23	178.6*	80.7	11.7	1.50*
4			0.70	101.4	66.9	9.7	1.10
5			0.85	123.1	75.8	11.0	1.10
6			1.17	169.0*	88.7	12.9*	1.37
7			0.73	106.2	62.6	9.1*	1.12
8			0.87	126.7	67.2	9.7	1.33
9			0.97	141.2	69.1	10.0	1.45*
10			1.13	164.2*	73.4	10.6	1.29
Average	60.13	0.93	0.81	117.5	72.2	10.5	1.22
Std. Dev.	0	0	0.11	15.4	5.0	0.7	0.13
2" Gage Length							
ONA221	60.13	0.93	0.77	111.1	73.3	10.6	1.01
2			0.82	119.5	68.2	9.9*	1.26*
3			0.95	137.6*	70.9	10.3	1.22
4			0.69	99.5	73.8	10.7	0.95
5			0.68	99.0	78.5	11.4*	0.87*
6			0.93	135.2*	76.4	11.5*	1.15
7			0.85	123.1	66.0	9.6*	1.28
8			0.85	123.1	73.3	10.6	1.14
9			0.61	88.4*	71.7	10.4	0.84*
10			0.64	92.9*	77.1	11.2	0.85*
Average	60.13	0.93	0.78	112.5	73.3	10.6	1.10
Std. Dev.	0	0	0.08	11.2	2.1	0.3	0.11
4" Gage Length							
ONA141	60.13	0.93	0.58	84.0*	75.8	11.0	0.76
2			0.74	107.7	78.8	11.4	0.96*
3			0.67	97.0	78.5	11.4	0.86
4			0.51	73.9*	76.1	11.0	0.66*
5			0.70	101.4	72.1	10.5*	0.98*
6			0.77	111.1*	84.9	12.3*	0.90
7			0.63	91.7	81.8	11.9	0.78
8			0.70	101.4	79.0	11.5	0.88
10			0.73	106.2	80.6	11.7	0.91
Average	60.13	0.93	0.70	100.9	78.6	11.4	0.85
Std. Dev.	0	0	0.04	5.9	2.2	0.3	0.06

* Numbers not used in calculating the Average or Standard Deviation.

Table A2

Individual Single Fiber Tensile Test Data for
Astroquartz 9288 at Elevated Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
500°C, 8" Gage Length							
5NA181	60.13	0.93	1.36	197.0	84.5	12.3	1.61
2			1.76	254.9*	84.9	12.3	2.06*
3			0.77	111.5	72.9	10.6	1.09
4			0.89	128.4	77.8	11.3	1.13
Average	60.13	0.93	1.19	145.7	80.1	11.6	1.28
Std. Dev.	0	0	0.31	45.3	5.8	0.8	0.29
500°C, 10" Gage Length							
5NA1101	60.13	0.93	1.64	237.1	84.2	12.2	1.93*
2			1.33	193.1	89.8	13.0*	1.45*
3			1.27	184.0*	84.5	12.2	1.50
4			1.58	229.3	82.7	12.0*	1.83
5			1.57	226.9	89.5	13.0*	1.74
Average	60.13	0.93	1.53	221.6	84.3	12.2	1.69
Std. Dev.	0	0	0.13	19.5	0.1	0.0	0.17
600°C, 8" Gage Length							
6NA181	60.13	0.93	1.54	222.6*	77.7	11.3*	1.96*
2			1.13	163.2	68.9	10.0	1.60
3			1.08	156.9	70.5	10.2	1.49
4			1.18	170.4	74.0	10.7	1.57
5			0.76	110.1*	70.4	10.2	1.07*
Average	60.13	0.93	1.13	163.5	71.0	10.3	1.55
Std. Dev.	0	0	0.05	6.8	2.2	0.3	0.06
700°C, 8" Gage Length							
7NA181	60.13	0.93	1.10	159.1	75.3	10.9	1.44
2			0.68	98.0*	69.8	10.1	1.02*
3			1.09	157.9	74.7	10.8	1.47
4			1.06	153.3	75.3	10.9	1.39
5			1.19	172.1*	71.9	10.4	1.70*
6			0.84	121.4	67.7	9.8*	1.25
Average	60.13	0.93	1.02	147.9	73.4	10.6	1.39
Std. Dev.	0	0	0.12	17.8	2.2	0.3	0.10

* Numbers not used in calculating the Average or Standard Deviation.

Table A2

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
800°C, 8" Gage Length							
8NA181	60.13	0.93	0.75	108.6	73.3	10.6	1.02*
2			0.93	134.2*	72.0	10.4	1.31
3			0.79	114.9	60.8	8.8	1.37
4			0.69	99.7*	71.9	10.4	1.15
5			0.84	121.4	57.3	8.3*	1.46*
Average	60.13	0.93	0.79	115.0	69.5	10.1	1.28
Std. Dev.	0	0	0.04	6.4	5.8	0.8	0.11

* Numbers not used in calculating the Average or Standard Deviation.

Table A3

Individual Single Fiber Tensile Test Data for Uncoated
Nicalon NLM-102 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
1" Gage Length							
ONA211C	149.57	2.32	2.37	344.0	211.9	30.7	1.07
2C			3.16	458.0*	240.2	34.8	1.33*
5C			2.32	335.8	214.0	31.0	1.09
7C			2.17	314.5	203.3	29.5*	1.06
9C			2.00	289.2*	253.0	36.7*	1.07
10C			2.41	349.4	227.1	32.9	1.14
Average	149.57	2.32	2.32	335.9	223.3	32.4	1.08
Std. Dev.	0	0	0.11	15.4	13.1	1.9	0.03
2" Gage Length							
ONA222C	149.57	2.32	2.42	351.2*	174.6	25.3*	1.38
3C			3.13	454.1*	325.3	47.2*	0.97*
4C			2.97	430.9	302.9	43.9*	0.98*
5C			2.52	365.2*	190.4	27.6	1.32
6C			2.80	405.8	204.8	29.7	1.35
7C			2.97	430.0	211.9	30.7	1.39
8C			2.78	402.4	235.7	34.2	1.19
Average	149.57	2.32	2.88	417.3	210.7	30.5	1.32
Std. Dev.	0	0	0.11	15.3	18.9	2.7	0.08
4" Gage Length							
ONA241C	149.57	2.32	2.06	299.0	202.3	29.3*	0.98
2C			2.24	324.6	223.8	32.4*	1.00
3C			2.59	375.4	249.9	36.2	1.04
4C			2.07	300.5	264.6	38.4	0.78
5C			3.14	454.6*	315.3	45.7*	0.99
6C			3.37	487.9*	335.8	48.7*	1.00
8C			1.64	238.2*	250.7	36.3	0.65*
9C			3.08	445.9	308.4	44.7	1.00
10C			2.25	326.6	284.9	41.3	0.78
Average	149.57	2.32	2.38	345.3	271.7	39.4	0.95
Std. Dev.	0	0	0.39	56.5	24.9	3.6	0.10

* Numbers not used in calculating Average and Standard Deviation.

Table A4

Individual Single Fiber Tensile Test Data for Uncoated
Nicalon NLM-102 at Elevated Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
1000°C, 8" Gage Length							
ONA281	149.57	2.32	1.87	271.0	277.2	40.2*	0.67
2			1.76	254.5	247.6	35.9	0.70
3			1.88	273.0	228.1	33.1	0.79
4			2.08	301.1*	271.8	39.4	0.77
5			1.43	206.5*	253.0	36.7	0.56*
6			1.80	261.3	223.0	32.3*	0.80
Average	149.57	2.32	1.83	265.0	250.2	36.3	0.75
Std. Dev.	0	0	0.06	8.6	18.0	2.6	.06
1000°C, 10" Gage Length							
ONA101	149.57	2.32	1.51	218.7	201.3	29.2	0.74
2			1.42	206.1	221.4	32.1	0.63
3			0.99	143.5*	207.1	30.0	0.48*
4			1.84	266.7*	262.8	38.1*	0.70
5			1.76	254.5	235.1	34.1	0.73
6			1.37	198.3	197.7	28.7	0.68
Average	149.57	2.32	1.51	219.4	212.5	30.8	0.70
Std. Dev.	0	0	0.17	24.9	15.5	2.2	0.04
1100°C, 8" Gage Length							
1NA281A	149.57	2.32	1.76	255.0	214.1	31.0	0.82
2A			1.34	194.4*	171.8	24.9*	0.79
3A			2.42	351.0	255.9	37.1	0.95
4A			1.54	223.0	212.2	30.8	0.73*
5A			2.61	378.7*	270.8	39.2*	0.96*
Average	149.57	2.32	1.91	276.4	227.4	33.0	0.85
Std. Dev.	0	0	0.46	66.6	24.7	3.6	0.09
1200°C, 8" Gage Length							
2NA281	149.57	2.32	1.49	215.3	145.0	21.0	1.04
2			1.02	148.4*	101.4	14.7*	1.02
3			1.49	215.3	115.0	16.7*	1.29*
4			1.40	203.1	155.7	22.6	0.92
5			1.82	263.8	223.0	32.3*	0.81*
6			1.59	230.3	205.9	29.8	0.78*
7			2.64	383.0*	234.3	34.0*	1.12
Average	149.57	2.32	1.56	225.5	168.8	24.5	1.02
Std. Dev.	0	0	0.16	23.4	32.5	4.7	0.08

* Numbers not used in calculating Average and Standard Deviation.

Table A4

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
1300°C, 8" Gage Length							
3NA281	149.57	2.32	1.02	148.4	136.4	19.8*	0.77
2			1.20	174.5	171.8	24.9	0.70
3			1.61	233.2	147.1	21.3	1.12*
4			2.05	297.2*	220.9	32.0*	0.94
5			0.81	116.8*	172.6	25.0	0.44*
Average	149.57	2.32	1.28	185.4	163.9	23.7	0.80
Std. Dev.	0	0	0.30	43.4	14.5	2.1	0.12

* Numbers not used in calculating Average and Standard Deviation.

Table A5

Individual Single Fiber Tensile Test Data for
Nextel 312 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
1" Gage Length							
031211	84.83	1.31	1.23	178.2	103.4	15.0	1.19
2			1.17	169.5	110.1	16.0	1.06
3			1.45	210.4	102.9	14.9	1.40
4			1.33	193.4	105.4	15.3	1.37
5			0.92	133.1*	105.7	15.3	0.89*
6			1.26	182.0	109.1	15.8	1.13
7			1.39	200.9	109.1	15.8	1.27
8			1.62	235.1*	111.6	16.2*	1.44
9			1.72	249.1*	97.1	14.1*	1.76*
10			1.16	168.0	98.8	14.3*	1.17
Average	84.83	1.31	1.28	186.0	106.5	15.4	1.25
Std. Dev.	0	0	0.11	16.1	2.9	0.4	0.14
2" Gage Length							
131221	84.83	1.31	1.05	151.7	116.7	16.9	0.89
2			1.05	151.7	117.5	17.0	1.03
3			1.72	249.1*	108.5	15.7	0.81*
4			1.72	249.1*	133.7	19.4*	1.29*
5			0.89	129.7	92.9	13.5*	0.96
6			1.05	151.7	112.0	16.2	0.92
8			1.55	224.8	137.1	19.9*	1.13
9			0.85	123.2	110.5	16.0	1.31*
10			0.85	123.2	97.4	14.1*	0.88
Average	84.83	1.31	1.04	150.8	113.0	16.4	0.97
Std. Dev.	0	0	0.24	35.2	3.9	0.6	0.10
4" Gage Length							
031241C	84.83	1.31	0.94	136.5	169.7	24.6*	0.56
2C			0.93	134.6	134.4	19.5	0.69
3C			1.36	197.2*	174.5	25.3*	0.78
4C			1.28	185.8*	140.1	20.3	0.91*
5C			0.06	9.4*	11.0	1.6*	0.58
6C			0.52	74.7	117.6	17.1	0.43*
7C			0.74	106.9	104.8	15.2	0.71
8C			0.72	104.6	115.2	16.7	0.63
9C			0.46	66.4	121.2	17.6	0.38*
10C			0.87	125.5	141.9	20.6	0.61
Average	84.83	1.31	0.74	107.0	125.0	18.1	0.65
Std. Dev.	0	0	0.19	27.9	14.0	2.0	0.08

* Numbers not used in calculating the Average or Standard Deviation.

Table A6

Individual Single Fiber Tensile Test Data for
Nextel 312 at Elevated Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
400°C, 8" Gage Length							
431281	84.83	1.31	1.11	160.4	154.6	22.4	0.72
2			1.11	161.1	152.0	22.0	0.73
3			1.06	153.9	150.8	21.9	0.70
4			1.09	157.7	164.9	23.9*	0.65
5			0.95	137.6*	160.1	23.2	0.59*
Average	84.83	1.31	1.09	158.3	154.3	22.4	0.70
Std. Dev.	0	0	0.02	3.3	4.1	0.6	0.04
500°C, 8" Gage Length							
531281	84.83	1.31	0.86	124.4	143.9	20.9	0.59
2			0.89	129.3	153.3	22.2*	0.58*
3			0.95	137.6	142.5	20.7	0.70
4			0.93	135.0	135.4	19.6*	0.70
5			0.98	142.2	139.5	20.2	0.69
6			1.28	185.0*	152.8	22.2*	0.84*
Average	84.83	1.31	0.92	133.7	142.0	20.6	0.67
Std. Dev.	0	0	0.05	7.0	2.3	0.3	0.05
500°C, 10" Gage Length							
5312101	84.83	1.31	1.28	186.2*	202.4	29.3*	0.62
2			0.70	101.6*	137.7	20.0	0.50*
3			0.98	142.2	147.9	21.4	0.66
4			1.08	156.6	145.9	21.2	0.72*
5			0.83	121.0	130.3	18.9	0.63
Average	84.83	1.31	0.97	139.9	140.5	20.4	0.64
Std. Dev.	0	0	0.12	17.9	8.1	1.2	0.02
600°C, 8" Gage Length							
631281	84.83	1.31	0.91	132.5*	167.8	24.3	0.54*
2			1.13	164.0	148.7	21.6	0.75*
3			0.89	129.5*	132.8	19.2*	0.65
4			1.14	165.7	166.9	24.2	0.68
5			1.17	169.5	161.9	23.5	0.71
Average	84.83	1.31	1.15	166.4	161.4	23.4	0.68
Std. Dev.	0	0	0.02	2.8	8.8	1.3	0.02

* Numbers not used in calculating the Average or Standard Deviation.

Table A6

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
700°C, 8" Gage Length							
731281	84.83	1.31	0.56	81.3*	103.1	14.9	1.27*
2			0.79	114.3	127.7	18.5*	1.18
3			0.75	108.8	111.5	16.2	1.12
4			0.86	125.1*	116.7	16.9	0.92*
5			0.72	104.3	86.4	12.5*	1.12
Average	84.83	1.31	0.75	109.1	110.4	16.0	1.14
Std. Dev.	0	0	0.03	5.0	6.9	1.0	0.03

* Numbers not used in calculating the Average or Standard Deviation.

Table A7

Individual Single Fiber Tensile Test Data for
Nextel 380 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
1" Gage Length							
038011	94.17	1.68	2.12	308.4*	143.2	20.8	1.49*
2			1.23	179.6	128.8	18.7	0.98*
3			1.11	160.2*	87.8	12.7*	1.26
4			1.52	221.0	122.8	17.8	1.22
5			2.00	290.0*	143.6	20.8	1.38
6			1.41	204.9	135.1	19.6	1.05
8			1.12	162.2*	129.7	18.8	0.86*
9			1.64	237.0	142.1	20.6	1.13
10			1.68	244.2	127.0	18.4	1.31
Average	94.17	1.68	1.50	217.3	134.0	19.4	1.22
Std. Dev.	0	0	0.16	23.2	8.2	1.2	1.11
2" Gage Length							
038021	94.17	1.68	1.03	148.9*	127.6	18.5*	0.81
2			1.59	230.5	153.6	22.3	1.03
3			1.30	187.8	130.0	18.8*	1.00
4			1.48	213.8	163.4	23.7*	0.91
5			1.62	235.3*	146.6	21.3	1.10*
6			0.91	131.5*	152.1	22.0	0.60*
7			1.74	251.7*	149.8	21.7	1.16*
8			1.00	145.2*	151.7	22.0	0.62*
9			1.34	194.0	153.2	22.2	0.87
10			1.26	182.0	135.0	19.6	0.93
Average	94.17	1.68	1.39	201.6	148.8	21.6	0.92
Std. Dev.	0	0	0.14	20.1	6.6	0.9	0.08
4" Gage Length							
038041	94.17	1.68	0.94	136.6	137.0	19.9	0.68*
2			1.13	163.9	127.5	18.5*	0.88
3			0.78	113.4*	132.5	19.2	0.60*
4			1.10	159.2	135.0	19.6	0.80
5			1.56	225.4*	147.5	21.4*	1.05*
6			1.14	165.6	132.8	19.3	0.85
7			1.47	213.1*	154.0	22.3*	0.95
8			1.21	175.9	142.0	20.6	0.85
9			1.05	152.3	130.4	18.9	0.80
Average	94.17	1.68	1.10	158.9	135.0	19.6	0.86
Std. Dev.	0	0	0.09	13.4	3.8	0.5	0.06

* Numbers not used in calculating the Average or Standard Deviation.

Table A8

Individual Single Fiber Tensile Test Data for
Nextel 380 at Elevated Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
600°C, 8" Gage Length							
638081	94.17	1.68	1.42	205.9	163.4	23.7	0.87
2			1.56	226.8	185.0	26.8*	0.85
3			1.54	223.0	164.5	23.8	0.94*
4			0.88	128.1*	156.6	22.7	0.58*
5			1.10	158.8	155.6	22.6	0.71
Average	94.17	1.68	1.40	203.6	160.0	23.2	0.81
Std. Dev.	0	0	0.22	31.2	4.4	0.7	0.07
600°C, 10" Gage Length							
6380101	94.17	1.68	1.30	187.8*	152.0	22.0	0.85
2			1.47	212.8*	163.0	23.6	0.93*
3			1.41	204.2	164.7	23.9	0.85
4			1.37	199.1	157.9	22.9	0.87
5			1.31	189.2	143.5	20.8*	0.88
Average	94.17	1.68	1.36	197.5	159.4	23.1	0.86
Std. Dev.	0	0	0.05	7.6	5.7	0.8	0.02
700°C, 8" Gage Length							
738081	94.17	1.68	1.72	249.0*	180.2	26.1*	0.96
2			1.13	163.9	145.5	21.1	0.79
3			1.53	221.3	148.6	21.5	1.01*
4			1.35	196.0	138.1	20.0	0.95
5			1.02	148.2*	133.2	19.3	0.75*
Average	94.17	1.68	1.34	193.8	141.3	20.5	0.90
Std. Dev.	0	0	0.20	28.8	6.1	0.9	0.10
800°C, 8" Gage Length							
838081	94.17	1.68	0.99	143.1*	145.9	21.1*	0.78
2			0.87	126.7	135.4	19.6	0.77
3			0.87	126.7	132.5	19.2	0.79
4			0.65	93.9*	121.0	17.5*	0.60*
5			0.74	106.9	122.5	17.8	0.68
6			0.94	136.6	129.0	18.7	0.82
Average	94.17	1.68	0.86	124.2	129.9	18.8	0.77
Std. Dev.	0	0	0.09	12.5	4.8	0.7	0.05

* Numbers not used in calculating the Average or Standard Deviation.

Table A8

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
900°C, 8" Gage Length							
938081	94.17	1.68	1.02	147.9	124.4	18.0	0.91*
2			0.77	111.7	129.0	18.7	0.62*
3			0.90	130.3	144.1	20.9*	0.75
4			1.08	156.9*	132.5	19.2	0.83
5			0.75	109.3*	122.5	17.8	0.64
Average	94.17	1.68	0.90	129.9	127.1	18.4	0.74
Std. Dev.	0	0	0.12	18.1	3.9	0.6	0.08

* Numbers not used in calculating the Average or Standard Deviation.

Table A9

Individual Single Fiber Tensile Test Data for
Nextel 440 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
1" Gage Length							
NX440101	88.22	1.37	0.58	83.8*	126.3	18.3*	0.46*
2			1.55	224.0	181.5	26.3	0.85
3			2.21	320.0	165.6	24.0	1.33*
5			1.22	177.0	188.4	27.3	0.65
6			2.42	351.0*	191.8	27.8	1.26
7			2.10	304.0	180.8	26.2	1.16
8			1.60	232.0	182.9	26.5	0.88
9			2.07	300.0	173.9	25.2	1.19
Average	88.22	1.37	1.79	260.0	180.8	26.2	1.00
Std. Dev.	0	0	0.39	56.8	8.8	1.3	0.24
2" Gage Length							
NX440201	88.22	1.37	1.90	276.0*	223.6	32.4*	0.85
3			1.76	255.0	186.3	27.0	0.94*
4			1.44	208.0	200.8	29.1	0.71
6			0.69	100.0*	176.0	25.5	0.39*
10			1.26	182.0	179.4	26.0	0.70
Average	88.22	1.37	1.48	215.0	185.6	26.9	0.75
Std. Dev.	0	0	0.26	37.0	11.0	1.6	0.08
4" Gage Length							
NX440401	88.22	1.37	1.18	171.0*	167.7	24.3	0.70*
2			1.70	247.0	194.6	28.2	0.88
3			2.30	333.0*	204.9	29.7	1.12
4			1.73	251.0	189.1	27.4	0.92
6			1.96	284.0	198.7	28.8	0.99
7			2.14	310.0	193.2	28.0	1.11
8			2.01	291.0	177.3	25.7	1.13*
9			1.93	280.0	189.8	27.5	1.02
10			1.88	273.0	200.1	29.0	0.94
Average	88.22	1.37	1.91	277.0	190.6	27.6	1.00
Std. Dev.	0	0	0.15	22.1	11.7	1.7	0.09

* Numbers not used in calculating the Average or Standard Deviation.

Table A10

Individual Single Fiber Tensile Test Data for
Nextel 440 at Elevated Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
500°C, 8" Gage Length							
044081B	88.22	1.37	0.77	112.1*	162.9	23.6*	0.47*
2			1.24	179.5	190.6	27.6	0.65
3			1.46	212.3	198.7	28.8	0.74
4B			1.57	226.9	215.9	31.3	0.73
5			1.74	252.4*	260.4	37.7*	0.67
6			1.60	232.4	213.8	31.0	0.75
7B			1.50	217.0	194.8	28.2	0.77
8			1.50	216.7	182.6	26.5	0.82
9			0.75	108.2*	192.7	27.9	0.39*
10B			1.63	236.8	175.5	25.4	0.93*
Average	88.22	1.37	1.50	217.4	195.6	28.3	0.73
Std. Dev.	0	0	0.13	18.9	13.9	2.0	0.06
500°C, 10" Gage Length							
0440101	88.22	1.37	0.99	143.1	186.3	27.0	0.53
2			1.12	162.1	172.1	24.9	0.65
3C			1.70	246.4*	179.0	25.9	0.95*
4			1.22	176.2	172.4	25.0	0.71
5			1.06	153.5	189.1	27.4	0.56
7			1.14	164.7	196.0	28.4	0.58
8			1.64	237.3*	192.6	27.9	0.85*
Average	88.22	1.37	1.10	159.9	183.8	26.6	0.61
Std. Dev.	0	0	0.09	12.4	9.6	1.4	0.07
600°C, 8" Gage Length							
144082	88.22	1.37	0.48	70.3	209.6	30.4	0.23*
3			0.24	35.1*	149.2	21.6*	0.16*
4			1.48	214.7*	211.6	30.7	0.70
5			1.66	240.9*	190.0	27.5	0.88*
6			0.97	141.0	199.6	28.9	0.49
7			0.78	113.4	178.9	25.9	0.44
Average	88.22	1.37	0.75	108.2	198.0	28.7	0.54
Std. Dev.	0	0	0.25	35.6	13.9	2.0	0.11

* Numbers not used in calculating the Average or Standard Deviation.

Table A10
(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
600°C, 10" Gage Length							
1440101	88.22	1.37	1.12	162.1	192.9	28.0	0.58
2			1.22	176.9	187.8	27.2	0.65
3			1.43	207.6	182.5	26.5	0.78
4			0.81	117.1*	171.9	24.9	0.47*
5			1.03	148.8	197.5	28.6	0.52*
6			1.65	238.9*	202.2	29.3	0.81
7			1.66	240.9*	201.5	29.2	0.82
8			1.47	212.8	188.3	27.3	0.78
Average	88.22	1.37	1.25	181.7	190.6	27.6	0.75
Std. Dev.	0	0	0.19	28.0	10.2	1.5	0.10
700°C, 8" Gage Length							
244081	88.22	1.37	1.44	208.9	178.8	25.9	0.81
2			1.60	231.6	195.1	28.3	0.82
3			1.01	145.7*	176.8	25.6	0.57*
4			1.54	223.8	173.9	25.2	0.89
5			1.66	240.9	198.5	28.8*	0.84
Average	88.22	1.37	1.56	226.3	181.2	26.3	0.84
Std. Dev.	0	0	0.09	13.5	9.5	1.4	3.56
700°C, 10" Gage Length							
2440101	88.22	1.37	0.38	54.9*	151.5	22.0*	0.25*
2			1.69	245.6	196.0	28.4	0.86
3			0.93	135.3	184.9	26.8	0.51
4			1.10	158.7	182.5	26.5	0.60
5			1.56	226.4	183.7	26.6	0.85
6			1.81	262.8*	197.1	28.6	0.92
Average	88.22	1.37	1.32	191.5	188.8	27.4	0.75
Std. Dev.	0	0	0.36	52.8	7.1	1.0	0.18

* Numbers not used in calculating the Average or Standard Deviation.

Table A10
(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
800°C, 8" Gage Length							
344081A	88.22	1.37	1.62	234.2	178.3	25.8	0.91
2			0.56	81.2*	194.9	28.2	0.29*
3			0.83	121.0	190.8	27.7	0.44
4A			1.80	260.2*	205.2	29.7*	0.88
5			1.38	200.4	170.2	24.7	0.81
6			1.52	220.4	173.8	25.2	0.88
7A			1.44	208.2	162.9	23.6	0.88
8			0.32	46.1*	113.0	16.4*	0.28*
Average	88.22	1.37	1.36	196.8	178.5	25.9	0.80
Std. Dev.	0	0	0.31	44.3	12.3	1.8	0.18
800°C, 10" Gage Length							
3440101	88.22	1.37	1.52	219.9	226.4	32.8*	0.67
2			1.18	170.7*	194.6	28.2	0.60*
3A			1.68	242.8	221.8	32.2*	0.75
4			1.78	258.1*	203.6	29.5	0.88*
5			1.25	180.8*	215.1	31.2	0.58*
6A			1.48	214.1	184.7	26.8*	0.80
7			1.43	206.6	205.1	29.7	0.69
8			1.56	226.4	199.0	28.8	0.78
9A			1.64	237.6	189.5	27.5*	0.86*
Average	88.22	1.37	1.55	224.5	203.5	29.5	0.74
Std. Dev.	0	0	0.10	13.8	7.7	1.1	0.06

* Numbers not used in calculating the Average or Standard Deviation.

Table A11

Individual Single Fiber Tensile Test Data for
Nextel 480 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
1" Gage Length							
048002B	72.04	1.11	2.87	415.6	189.4	27.5	1.51
3B			2.57	372.2	172.5	25.0*	1.49
4B			2.83	410.7	163.3	23.7*	1.73*
5B			2.76	400.5	212.4	30.8	1.30
6B			2.62	379.5	208.3	30.2	1.24
7B			2.35	340.2*	205.0	29.7	1.13
8B			2.12	306.7*	217.0	31.5	0.95*
9B			2.99	434.0*	213.2	30.9	1.38
10B			2.74	397.3	225.4	32.7*	1.22
Average	72.04	1.11	2.73	396.0	207.5	30.1	1.32
Std. Dev.	0	0	0.12	17.1	9.8	1.4	0.13
2" Gage Length							
048021B	72.04	1.11	1.81	262.5	231.6	33.6	0.77
3B			1.69	244.2	204.0	29.6*	0.73
4B			2.77	401.8*	238.8	34.6*	1.15*
5B			1.78	258.1	194.0	28.1*	0.91
6B			2.28	330.4	225.8	32.7	1.00
7B			2.59	375.5*	233.8	33.9	1.09*
8B			2.00	290.2	216.0	31.3	0.91
9B			1.37	199.1*	234.1	33.9	0.58*
10B			1.95	282.2	216.9	31.4	0.89
Average	72.04	1.11	1.92	277.9	226.4	32.8	0.87
Std. Dev.	0	0	0.21	30.6	8.3	1.2	0.10
4" Gage Length							
048041	72.04	1.11	1.93	280.0	236.0	34.2	0.82
2			1.59	229.9*	213.8	31.0*	0.74
3			1.95	282.6	254.1	36.8*	0.77
4			2.35	340.2*	218.9	31.7	1.07*
5			2.16	313.4	231.4	33.5	0.93
6			2.39	346.0*	211.8	30.7*	1.13*
7			2.09	303.6	219.2	31.8	0.95
8			2.34	339.3*	249.3	36.1*	0.94
9			1.51	218.8*	227.0	32.9	0.61*
10			1.36	197.8*	229.0	33.2	0.60*
Average	72.04	1.11	2.03	294.9	226.9	32.9	0.86
Std. Dev.	0	0	0.11	16.2	6.2	0.9	0.09

* Numbers not used in calculating the Average or Standard Deviation.

Table A12

Individual Single Fiber Tensile Test Data for
Nextel 480 at Elevated Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
900°C, 8" Gage Length							
948081	72.04	1.11	1.73	251.4	224.8	32.6	0.78
2			1.61	233.5	278.6	40.4*	0.57*
3			1.90	275.9*	262.6	38.1	0.72
4			1.51	218.8*	217.2	31.5	0.68
5			1.85	268.3	226.4	32.8	0.81*
Average	72.04	1.11	1.73	251.1	232.8	33.7	0.73
Std. Dev.	0	0	0.12	17.4	20.3	2.9	0.05
1000°C, 8" Gage Length							
048081A	72.04	1.11	0.75	108.9*	188.4	27.3*	0.40*
2A			1.86	269.9	302.2	43.8*	0.62
3A			1.91	276.4	291.2	42.2	0.65
4A			1.56	226.6	213.6	31.0	0.73
5A			1.62	234.4	216.5	31.4	0.75
Average	72.04	1.11	1.74	251.8	240.4	34.8	0.69
Std. Dev.	0	0	0.17	25.0	44.0	6.4	0.05
1000°C, 10" Gage Length							
0480101A	72.04	1.11	1.21	174.8	236.9	34.3	0.50
2A			0.86	124.1*	267.0	38.7*	0.32*
3A			1.52	220.6*	253.4	36.7	0.60
4A			1.16	168.5	232.8	33.7	0.50
5A			1.26	182.6	202.2	29.3*	0.62*
6A			0.84	121.4*	221.3	32.1	0.38
Average	72.04	1.11	1.21	175.3	236.1	34.2	0.50
Std. Dev.	0	0	0.05	7.0	13.3	1.9	.09
1100°C, 8" Gage Length							
148081	72.04	1.11	0.22	32.4*	169.5	24.6	0.13*
2			0.36	52.7	178.4	25.9	0.19
3			0.51	74.6	168.4	24.4	0.31
4			0.46	67.0	190.9	27.7	0.22
5			0.75	109.4*	210.6	30.5*	0.38*
Average	72.04	1.11	0.45	64.7	176.8	25.6	0.24
Std. Dev.	0	0	0.08	11.1	10.4	1.5	0.06

* Numbers not used in calculating the Average or Standard Deviation.

Table A12

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
1200°C, 8" Gage Length							
248081A	72.04	1.11	0.20	28.6*	220.9	32.0	0.08*
2A			0.56	81.5	220.9	32.0	0.25
3A			0.55	80.4	220.9	32.0	0.25
4A			0.34	48.7	175.1	25.4*	0.18
5A			0.27	39.1	210.8	30.6	0.13
6A			0.54	78.1	208.0	30.2	0.29*
Average	72.04	1.11	0.45	65.5	216.3	31.4	0.20
Std. Dev.	0	0	0.14	20.1	6.4	0.9	0.06

* Numbers not used in calculating the Average or Standard Deviation.

Table A13

Individual Single Fiber Tensile Test Data for
Uncoated Nextel 480 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
1" Gage Length							
048011A	72.04	1.11	2.22	322.2	243.2	35.3	0.92
2A			2.29	331.9	224.0	32.5	1.01
3A			2.00	290.0*	227.0	32.9	0.88*
4A			3.04	440.0*	239.0	34.6	1.26*
5A			2.91	422.2	221.7	32.1*	1.32*
6A			2.78	403.4	232.3	33.7	1.20
7			2.09	303.4*	234.2	33.9	0.87*
8			3.14	455.6*	259.1	37.6*	1.21
9			2.51	364.5	240.7	34.9	1.07
10			2.38	344.5	228.9	33.2	1.04
Average	72.04	1.11	2.52	364.8	233.7	33.9	1.07
Std. Dev.	0	0	0.28	40.2	6.9	1.0	0.11
2" Gage Length							
048021	72.04	1.11	2.39	346.7	299.9	43.5*	0.80
2			2.88	416.7	302.8	43.9*	0.96
3			3.28	475.6*	307.7	44.6*	1.06
4			2.63	381.1	277.1	40.2	0.95
5			2.15	311.1	231.3	33.5	0.92
6			2.63	381.1	201.9	29.3*	1.35*
7			1.72	248.9*	227.6	33.0	0.75*
8			2.15	311.1	222.8	32.3	0.96
9			2.42	351.1	249.8	36.2	0.98
10			2.09	303.4	259.0	37.5	0.81
Average	72.04	1.11	2.42	350.3	244.6	35.4	0.93
Std. Dev.	0	0	0.28	40.7	21.1	3.1	0.09
4" Gage Length							
048042	72.04	1.11	1.52	221.0	271.0	39.3	0.57
4			1.29	187.5*	283.1	41.0	0.46*
6			1.77	256.7	336.7	48.8*	0.53
7			2.39	346.9*	310.3	45.0	0.77
9			2.43	352.7*	262.9	38.1	0.92*
10			1.86	270.1	252.7	36.6*	0.73
Average	72.04	1.11	1.72	249.3	281.8	40.8	0.62
Std. Dev.	0	0	0.18	25.4	20.7	3.0	0.12

* Numbers not used in calculating Average and Standard Deviation

Table A14

Individual Single Fiber Tensile Test Data for
Boron-Nitride Coated Nicalon NLM-102 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
1" Gage Length							
NLM102	174.37	2.70	1.12	162.0*	133.9	19.4	0.84*
3			2.01	291.0	120.8	17.5	1.66
4			1.64	237.0	97.3	14.1*	1.68
5			1.89	274.0	107.0	15.5	1.76
6			2.49	361.0	211.8	30.7*	1.18
7			1.89	274.0	122.1	17.7	1.55
8			2.82	409.0*	140.1	20.3	2.02*
10			1.95	282.0	147.7	21.4	1.32
Average	174.37	2.70	1.98	287.0	128.3	18.6	1.52
Std. Dev.	0	0	0.28	40.9	14.8	2.1	0.23
2" Gage Length							
NLM201	174.37	2.70	2.01	291.0*	142.1	20.6*	1.41
3			2.48	359.0	146.3	21.2*	1.69*
4			3.57	518.0	244.3	35.4	1.46
5			1.89	274.0*	196.0	28.4	0.97*
6			2.66	386.0	174.6	25.3	1.53
7			3.34	484.0	305.7	44.3*	1.09*
8			2.28	331.0	206.3	29.9	1.11
9			4.61	668.0*	308.4	44.7*	1.50
10			3.21	465.0	226.3	32.8	1.42
Average	174.37	2.70	2.93	424.0	209.8	30.4	1.41
Std. Dev.	0	0	0.52	75.4	26.9	3.9	0.15
4" Gage Length							
NLM401	174.37	2.70	2.55	370.0	255.6	32.7	1.13
2			2.86	415.0*	289.1	41.9*	0.99*
3			2.82	409.0*	196.0	28.4	1.44*
4			2.15	312.0	167.7	24.3	1.28
5			1.95	282.0	142.8	20.7*	1.36
6			1.84	266.0	184.9	26.8	0.99*
7			1.66	241.0*	172.5	25.0	0.97*
9			2.24	324.0	155.9	22.6	1.43*
Average	174.37	2.70	2.15	311.0	183.5	26.6	1.26
Std. Dev.	0	0	0.28	40.4	24.8	3.6	0.12

* Numbers not used in calculating the Average or Standard Deviation.

Table A15

Individual Single Fiber Tensile Test Data for
Boron-Nitride Coated Nicalon NLM-102 at Elevated Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
500°C, 8" Gage Length							
ONLM182	174.37	2.70	0.91	132.3	85.9	12.5	1.06
3			0.65	94.0*	54.6	7.9*	1.19*
4			0.90	130.2	80.7	11.7	1.11
5			0.63	91.5	87.1	12.6	0.73*
7			0.89	128.9	98.2	14.2*	0.91
Average	174.37	2.70	0.90	130.5	84.9	12.3	1.03
Std. Dev.	0	0	0.01	1.7	3.4	0.5	0.10
500°C, 10" Gage Length							
ONLM1101	174.37	2.70	2.05	297.4	205.2	29.7	1.00
2			1.96	284.1	186.6	27.1	1.05
3			1.59	230.8	193.1	28.0	0.82
4			1.16	168.5*	183.1	26.5	0.63*
9			1.81	261.6	148.6	21.5*	1.21*
10			1.92	278.7	211.3	30.6*	0.91
Average	174.37	2.70	1.87	270.5	192.0	27.8	0.95
Std. Dev.	0	0	0.18	25.6	9.7	1.4	0.10
600°C, 8" Gage Length							
1NLM181	174.37	2.70	0.95	137.3*	151.5	22.0	0.63*
2			1.13	163.9	153.3	22.2	0.74
3			2.93	424.2*	230.7	33.4*	1.27*
4			1.56	225.4	179.1	26.0	0.87
5			1.38	199.6	183.7	26.6	0.75
6			2.22	321.1	179.1	26.0	1.24*
7			1.14	165.5	140.6	20.4*	0.81
8			1.29	186.3	136.2	19.7*	0.94
9			1.43	208.0	158.4	23.0	0.91
10			2.18	316.1	190.7	27.6	1.14
Average	174.37	2.70	1.54	223.2	170.8	24.8	0.88
Std. Dev.	0	0	0.43	62.3	16.0	2.3	0.14

* Numbers not used in calculating the Average or Standard Deviation.

Table A15

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
600°C, 10" Gage Length							
1NLM1101	174.37	2.70	1.61	232.9	172.8	25.0	0.93
2			2.05	297.4*	190.0	27.5*	1.08
3			1.55	224.6	140.9	20.4*	1.10
4			1.46	212.1*	168.2	24.4	0.87*
5			1.58	228.8	158.6	23.0	0.99
6			1.84	266.2	144.6	21.0*	1.27*
7			1.73	251.2	162.8	23.6	1.06
Average	174.37	2.70	1.66	240.7	165.6	24.0	1.03
Std. Dev.	0	0	0.12	17.5	6.4	0.9	0.07
700°C, 8" Gage Length							
2NLM181	174.37	2.70	1.52	220.9*	157.3	22.8	0.97*
2			1.88	272.4	196.6	28.5	0.96*
3			2.13	308.2	170.2	24.7	1.25*
4			2.64	382.7*	215.6	31.2*	1.22*
5			2.38	345.2	204.9	29.7	1.16
6			1.41	204.6*	149.6	21.7*	0.94*
7			2.41	349.4	197.8	28.7	1.22*
8			1.45	210.0*	136.3	19.8*	1.06
9			2.00	290.3	186.4	27.0	1.08
Average	174.37	2.70	2.16	313.1	185.5	26.9	1.10
Std. Dev.	0	0	0.23	33.7	18.3	2.7	0.05
700°C, 10" Gage Length							
2NLM1106	174.37	2.70	1.81	262.0	170.6	24.7*	1.06
7			1.66	240.0	191.4	27.7	0.86
8			2.35	341.1*	208.2	30.2	1.13*
9			1.11	161.4*	178.2	25.8	0.63*
10			1.43	207.5	210.6	30.5*	0.68
Average	174.37	2.70	1.63	236.5	192.6	27.9	0.87
Std. Dev.	0	0	0.19	27.4	15.1	2.2	0.19

* Numbers not used in calculating the Average or Standard Deviation.

Table A15

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
800°C, 8" Gage Length							
3NLM181	174.37	2.70	1.66	241.2	115.8	16.8	1.44*
2			1.12	162.2	167.4	24.3	0.67*
3			1.16	168.5	112.1	16.2*	1.04
4			1.00	145.6*	119.0	17.3	0.84
5			1.02	148.5*	122.3	17.7	0.84
6			1.87	270.4*	192.6	27.9*	0.97
7			1.94	280.8*	202.6	29.4*	0.96
8			1.66	241.2	166.4	24.1	1.00
Average	174.37	2.70	1.40	203.3	138.2	20.0	0.94
Std. Dev.	0	0	0.30	43.9	26.3	3.8	0.08
800°C, 10" Gage Length							
3NLM1102	174.37	2.70	2.32	336.9	194.5	28.2	1.19*
4			0.77	111.9*	129.7	18.8*	0.59*
5			1.92	278.3	224.5	32.5	0.86
6			2.32	336.1	225.1	32.6	1.03
7			1.23	178.9	144.3	20.9*	0.86
8			2.41	349.4	219.1	31.8	1.10
Average	174.37	2.70	2.04	295.9	215.8	31.3	0.96
Std. Dev.	0	0	0.49	71.0	14.5	2.1	0.12

* Numbers not used in calculating the Average or Standard Deviation.

Table A16

Individual Single Fiber Tensile Test Data for
Boron-Nitride Coated Nextel 312 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
1" Gage Length							
0312101	88.22	1.37	1.61	233.0*	161.5	23.4	1.00
2			1.46	212.0	153.2	22.2	0.96
3			1.15	166.0	176.0	25.5	0.65
4			0.92	134.0*	154.6	22.4	0.60*
6			1.30	189.0	157.3	22.8	0.83
7			1.55	224.0	160.1	23.2	0.97*
8			0.91	132.0*	146.3	21.2	0.62
9			1.32	191.0	188.4	27.3	0.70
Average	88.22	1.37	1.35	196.0	162.2	23.5	0.79
Std. Dev.	0	0	0.15	22.4	13.6	2.0	0.16
2" Gage Length							
0312201	88.22	1.37	1.44	208.0*	182.2	26.4	0.79*
4			0.88	127.0	160.1	23.2	0.55
5			0.75	109.0*	159.4	23.1	0.47*
7			1.26	182.0	187.0	27.1	0.67
8			1.35	196.0	180.1	26.1	0.75
10			1.07	155.0	162.8	23.6	0.66
Average	88.22	1.37	1.14	165.0	171.9	24.9	0.66
Std. Dev.	0	0	0.21	30.5	12.5	1.8	0.08
4" Gage Length							
0312401	88.22	1.37	0.79	115.0*	161.5	23.4	0.49*
2			1.58	229.0*	164.2	23.8	0.97*
3			1.18	171.0	180.1	26.1	0.66
4			1.13	164.0	160.1	23.2	0.71
5			1.15	166.0	171.1	24.8	0.67
6			1.41	204.0	171.8	24.9	0.82
7			1.12	163.0	165.6	24.0	0.68
8			1.51	219.0*	190.4	27.6	0.79
10			1.00	145.0	168.4	24.4	0.60
Average	88.22	1.37	1.17	169.0	170.4	24.7	0.70
Std. Dev.	0	0	0.13	19.4	9.7	1.4	0.08

* Numbers not used in calculating the Average and Standard Deviation.

Table A17

Individual Single Fiber Tensile Test Data for
Boron-Nitride Coated Nextel 312 at Elevated Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
500°C, 8" Gage Length							
OBN3181	88.22	1.37	1.18	171.5*	164.6	23.9	0.72*
2			1.15	167.0	167.5	24.3	0.69
3			0.98	142.7	164.1	23.8	0.60
4			1.15	166.5	171.8	24.9*	0.67
5			0.97	140.5*	161.6	23.4*	0.60
6			1.01	145.7	165.8	24.0	0.61
Average	88.22	1.37	1.07	155.5	165.5	24.0	0.63
Std. Dev.	0	0	0.09	13.1	1.5	0.2	0.04
500°C, 10" Gage Length							
OBN31102	88.22	1.37	0.51	73.4*	166.0	24.1	0.30*
3			1.22	176.9*	180.8	26.2*	0.67
4			0.76	109.8	168.4	24.4	0.45
5			1.06	154.0	156.3	22.7	0.68
8			1.06	153.5	160.5	23.3	0.66
9			1.02	148.3	155.0	22.5	0.66
10			0.97	140.5	155.1	22.5	0.63
Average	88.22	1.37	0.97	141.2	160.2	23.2	0.63
Std. Dev	0	0	0.13	18.4	5.8	0.8	0.09
600°C, 8" Gage Length							
1BN3181	88.22	1.37	1.08	156.1	172.4	25.0	0.63
2			0.96	139.7*	160.7	23.3*	0.60
3			1.06	153.5	188.3	27.3*	0.56*
4			1.04	151.2	175.7	25.5	0.59
5			1.13	163.9	167.5	24.3	0.68
6			1.07	155.1	169.5	24.6	0.63
7			1.25	181.9*	177.7	25.8	0.71*
Average	88.22	1.37	1.08	156.0	172.6	25.0	0.63
Std. Dev.	0	0	0.03	4.8	4.2	0.6	0.04

* Numbers not used in calculating the Average and Standard Deviation.

Table A17

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
600°C, 10" Gage Length							
1BN31101	88.22	1.37	0.89	128.8	164.6	23.9	0.54
2			0.91	132.2	165.8	24.0	0.55
3			0.92	132.7	147.7	21.4*	0.62
4			0.52	75.5	170.7	24.7	0.30
5			0.98	142.3	173.8	25.2*	0.56
6			1.03	149.6	163.9	23.8	0.63
7			0.27	39.0*	168.3	24.4	0.16*
Average	88.22	1.37	0.88	126.8	166.7	24.2	0.53
Std. Dev.	0	0	0.18	26.3	2.8	0.4	0.12
700°C, 8" Gage Length							
2BN3181	88.22	1.37	1.25	181.9	170.2	24.7	0.74
3			1.45	210.8*	160.5	23.3	0.91*
4			1.13	163.9	190.5	27.6*	0.59
5			0.50	72.9*	146.2	21.2*	0.34*
6			1.10	158.7	159.3	23.1	0.69
7			0.61	88.7*	163.3	23.7	0.37*
8			1.36	197.7	186.6	27.0*	0.73
9			1.01	145.7	153.2	22.2	0.66
10			1.15	167.3	190.4	27.6*	0.61
Average	88.22	1.37	1.17	169.2	161.3	23.4	0.67
Std. Dev.	0	0	0.13	18.3	6.2	0.9	0.06
700°C, 10" Gage Length							
2BN31104	88.22	1.37	1.05	152.2	181.1	26.2*	0.58
5			1.18	171.7	161.2	23.4	0.74
6			1.02	148.3	146.2	21.2	0.70
7			0.93	135.3	177.8	25.8*	0.52*
8			1.34	193.6*	162.9	23.6	0.82*
9			1.01	145.7	143.7	20.8	0.70
10			0.83	119.7*	142.4	20.6*	0.58
Average	88.22	1.37	1.04	150.6	153.5	22.2	0.66
Std. Dev.	0	0	0.09	13.3	10.0	1.4	0.07

* Numbers not used in calculating the Average and Standard Deviation.

Table A17

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
800°C, 8" Gage Length							
3BN3181	88.22	1.37	1.13	164.4	181.5	26.3	0.63
2			0.97	140.5	172.4	25.0	0.56
3			1.22	176.4	173.9	25.2	0.70
4			1.08	156.1	152.5	22.1	0.71
5			1.01	145.7	189.3	27.4*	0.53*
6			0.66	96.3*	131.2	19.0*	0.51*
7			1.25	181.1	163.9	23.8	0.76*
8			1.03	148.8	159.5	23.1	0.64
9			1.28	185.3*	182.6	26.5	0.70
Average	88.22	1.37	1.10	159.0	169.5	24.6	0.66
Std. Dev.	0	0	0.11	15.6	11.3	1.6	0.06
800°C, 10" Gage Length							
3BN31101	88.22	1.37	0.94	136.1	147.9	21.4	0.63
2			1.10	159.5*	180.4	26.2*	0.61*
3			0.99	143.1	151.9	22.0	0.65
4			1.05	152.2	152.2	22.1	0.69*
5			0.92	134.0	150.4	21.8	0.61
6			0.87	125.4*	131.1	19.0*	0.66
Average	88.22	1.37	0.98	141.3	150.6	21.8	0.64
Std. Dev.	0	0	0.06	8.2	2.0	0.3	0.02

* Numbers not used in calculating the Average and Standard Deviation.

Table A18

Individual Single Fiber Tensile Test Data for
Boron-Nitride Coated Nextel 440 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
1" Gage Length							
BN440102	115.10	1.78	1.09	158.0	137.3	19.9	0.79
4			0.97	140.0	136.6	19.8	0.70
5			0.49	71.2*	124.9	18.1	0.39
6			1.46	212.0	139.4	20.2	1.05*
7			1.66	240.0*	603.8	87.5*	0.27*
Average	115.10	1.78	1.17	170.0	134.6	19.5	0.63
Std. Dev.	0	0	0.26	37.5	6.5	0.9	0.21
2" Gage Length							
BN440201	115.10	1.78	1.73	251.0*	146.3	21.2	1.18*
2			1.59	230.0	139.4	20.2	1.14
4			1.34	194.0	143.5	20.8	0.94
9			0.81	117.0	190.4	27.6*	0.43*
10			0.65	94.3*	121.4	17.6*	0.54
Average	115.10	1.78	1.24	180.0	142.8	20.7	0.87
Std. Dev.	0	0	0.40	57.7	3.5	0.5	0.31
4" Gage Length							
BN440401	115.10	1.78	0.83	120.0*	149.0	21.6	0.55*
2			0.81	117.0*	147.7	21.4	0.54*
3			0.97	140.0	159.4	23.1	0.61
4			1.17	170.0	147.0	21.3	0.80
5			1.26	182.0	153.9	22.3	0.81
6			1.14	165.0	135.9	19.7	0.84
7			0.81	117.0*	123.5	17.9	0.65
9			1.40	203.0*	151.1	21.9	0.92*
10			1.50	217.0*	150.4	21.8	1.00*
Average	115.10	1.78	1.13	164.0	146.4	21.2	0.74
Std. Dev.	0	0	0.12	17.7	10.6	1.5	0.10

* Numbers not used in calculating Average and Standard Deviation.

Table A19

Individual Single Fiber Tensile Test Data for
Boron-Nitride Coated Nextel 440 at Elevated Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
500°C, 8" Gage Length							
OBN4481A	115.10	1.78	0.50	72.0*	137.0	19.9	0.36*
2			0.67	96.7	169.5	24.6*	0.39
3			0.69	99.7	141.1	20.5	0.49
4A			0.61	88.7	144.1	20.9	0.43
5			0.57	82.6	151.9	22.0	0.37
6			0.84	121.1*	146.8	21.3	0.57*
7A			0.68	97.9	116.3	16.9*	0.58*
Average	115.10	1.78	0.64	93.1	144.2	20.9	0.42
Std. Dev.	0	0	0.05	7.2	5.7	0.8	0.05
500°C, 10" Gage Length							
OBN44101	115.10	1.78	0.83	120.3	146.8	21.3	0.56
2			0.88	127.8	138.9	20.1	0.63*
3A			0.77	112.3	151.9	22.0	0.51
4			0.59	85.8*	128.6	18.6	0.46*
5			1.09	158.5*	190.2	27.6*	0.57
Average	115.10	1.78	0.83	120.1	141.6	20.5	0.55
Std. Dev.	0	0	0.05	7.8	10.1	1.5	0.03
600°C, 8" Gage Length							
1BN4481	115.10	1.78	0.85	122.8*	171.7	24.9*	0.49
2			0.89	129.6*	168.4	24.4	0.53*
3			0.66	95.7	167.7	24.3	0.39
4			0.83	120.7	153.1	22.2	0.54*
5			0.49	70.8	156.3	22.7	0.31*
6			0.35	50.7*	139.8	20.3*	0.25*
7			0.44	63.8*	125.8	18.2*	0.35
8			0.70	101.7	160.4	23.3	0.44
9			0.72	103.7	148.7	21.6	0.48
10			0.65	93.7	159.2	23.1	0.41
Average	115.10	1.78	0.67	97.7	159.1	23.1	0.43
Std. Dev.	0	0	0.11	16.3	7.2	1.0	0.05
600°C, 10" Gage Length							
1BN44101	115.10	1.78	0.82	119.1	182.6	26.5*	0.45
2			1.02	147.6*	166.9	24.2	0.61
4			0.87	126.6	146.8	21.3	0.59
5			0.33	48.1*	132.6	19.2	0.25*
6			0.50	72.2	132.8	19.3	0.37
7			0.92	132.6	148.8	21.6	0.61*
Average	115.10	1.78	0.78	112.6	145.6	21.1	0.51
Std. Dev.	0	0	0.19	27.5	14.1	2.0	0.11

* Numbers not used in calculating Average and Standard Deviation.

Table A19

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
700°C, 8" Gage Length							
2BN4481	115.10	1.78	0.74	107.7	156.4	22.7	0.47
2			0.85	123.6	148.4	21.5	0.57
3			0.81	117.3	142.3	20.6*	0.57
4			0.46	67.0*	137.0	19.9*	0.34*
5			1.00	145.6*	157.6	22.8	0.64*
6			0.66	95.9	155.7	22.6	0.43
7			0.87	125.6	161.3	23.4*	0.54
8			0.89	128.6	147.9	21.4	0.60
9			0.86	124.2	165.3	24.0*	0.52
10			0.67	96.5	152.2	22.1	0.44
Average	115.10	1.78	0.79	114.9	153.0	22.2	0.52
Std. Dev.	0	0	0.09	13.2	4.2	0.6	0.06
700°C, 10" Gage Length							
2BN44101	115.10	1.78	0.69	99.7	149.6	21.7	0.46
2			0.95	137.0*	164.4	23.8*	0.57
3			0.67	97.1	131.4	19.0	0.51
4			0.43	61.8*	155.1	22.5	0.27*
5			0.50	72.4*	144.8	21.0	0.34*
7			0.63	91.7	127.9	18.5*	0.49
8			0.80	116.7	128.8	18.7*	0.63*
9			0.66	96.3	146.1	21.2	0.45
10			0.74	107.7	142.9	20.7	0.52
Average	115.10	1.78	0.70	101.5	145.0	21.0	0.50
Std. Dev.	0	0	0.06	9.1	7.9	1.1	0.04
800°C, 8" Gage Length							
3BN4481	115.10	1.78	0.88	127.6	160.1	23.2	0.55
2			0.95	137.6	147.5	21.4	0.64
3			0.98	142.0	182.3	26.4*	0.54
4			0.62	89.7	117.9	17.1	0.52
5			0.30	43.9*	121.1	17.6	0.25*
6			0.75	108.3	132.8	19.3	0.56
7			0.77	111.7	112.1	16.2*	0.69
8			1.00	145.6	143.5	20.8	0.70*
Average	115.10	1.78	0.85	123.2	137.2	19.9	0.58
Std. Dev.	0	0	0.14	20.6	16.3	2.4	0.07

* Numbers not used in calculating Average and Standard Deviation.

Table A19

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
800°C, 10" Gage Length							
3BN44103	115.10	1.78	0.77	111.1	131.0	19.0*	0.58
4			0.94	135.8	154.9	22.5	0.60
5			0.88	126.8	152.2	22.1	0.57
6			0.65	93.9*	154.3	22.4	0.42*
7			0.81	117.5	143.5	20.8	0.56
9			1.00	144.8*	163.7	23.7*	0.61
Average	115.10	1.78	0.85	122.8	151.2	21.9	0.59
Std. Dev.	0	0	0.07	10.8	5.3	0.8	0.02

* Numbers not used in calculating Average and Standard Deviation.

Table A20

Individual Single Fiber Tensile Test Data for
Boron-Nitride Coated Nextel 480 at Room Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
1" Gage Length							
0480101	106.58	1.65	1.86	270.0*	171.8	24.9	1.08*
2			1.36	197.0	198.0	28.7	0.69
3			0.70	102.0*	179.4	26.0	0.39*
4			0.91	132.0	167.0	24.2	0.55
5			0.88	128.0	172.5	25.0	0.51
6			1.61	234.0	164.2	23.8	0.98*
7			1.35	196.0	171.1	24.8	0.79
8			1.64	237.0	171.1	24.8	0.96*
10			0.99	143.0	185.6	26.9	0.53
Average	106.58	1.65	1.25	181.0	175.9	25.5	0.61
Std. Dev.	0	0	0.32	46.7	10.5	1.5	0.12
2" Gage Length							
0480201	106.58	1.65	1.19	172.0*	166.3	24.1	0.71*
2			1.04	151.0	183.5	26.6	0.57
3			0.86	124.0	154.6	22.4	0.55
4			0.91	132.0	157.3	22.8	0.58
5			1.00	145.0	152.5	22.1	0.66
6			0.99	143.0	141.5	20.5	0.70
7			0.59	85.0*	148.4	21.5	0.40*
8			1.05	152.0	187.7	27.2	0.56
9			1.04	151.0	163.5	23.7	0.64
10			1.05	152.0	147.0	21.3	0.71
Average	106.58	1.65	0.99	144.0	160.2	23.2	0.62
Std. Dev.	0	0	0.07	10.5	15.3	2.2	0.06
4" Gage Length							
0480402	106.58	1.65	1.21	176.0	240.8	34.9	0.50
3			1.56	226.0	271.2	39.3*	0.58
4			1.02	148.0	180.8	26.2	0.57
5			1.08	157.0	176.6	25.6*	0.61
6			1.46	211.0	197.3	28.6	0.74*
7			1.08	157.0	213.9	31.0	0.51
8			1.83	265.0*	228.4	33.1	0.80*
9			0.86	124.0*	193.9	28.1	0.44*
Average	106.58	1.65	1.24	179.0	209.1	30.3	0.55
Std. Dev.	0	0	0.22	32.2	22.7	3.3	0.05

* Numbers not used in calculating the Average or Standard Deviation.

Table A21

Individual Single Fiber Tensile Test Data for
Boron-Nitride Coated Nextel 480 at Elevated Temperature

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
500°C, 8" Gage Length							
OBN4881A	106.58	1.65	1.20	174.5*	209.3	30.3	0.57
2			1.08	157.2	192.9	28.0	0.56
3			0.86	124.2	217.7	31.6*	0.39
4A			1.13	164.3*	187.1	27.1	0.61*
5			1.04	150.8	203.1	29.4	0.51
6			0.89	128.4	152.4	22.1*	0.58
7			0.53	77.1*	163.8	23.7*	0.32*
8			0.54	78.7*	206.7	30.0	0.26*
9			0.94	135.7	161.0	23.3*	0.58
10			0.75	108.1	175.4	25.4	0.43
Average	106.58	1.65	0.92	134.1	195.7	28.4	0.52
Std. Dev.	0	0	0.12	18.0	13.1	0.9	0.08
500°C, 10" Gage Length							
OBN48101	106.58	1.65	0.98	142.2	206.5	29.9	0.47
2			0.46	66.8*	192.0	27.8	0.24*
3			1.17	170.1*	190.9	27.7	0.61*
4			1.16	168.0*	229.6	33.3*	0.51
5			0.84	121.9	195.6	28.4	0.43
6			0.81	118.0	175.1	25.4*	0.47
7			0.72	103.8	193.6	28.1	0.37
8			0.96	138.7	187.7	27.2	0.51
9			0.74	107.7	193.0	28.0	0.38
10			0.77	112.0	193.2	28.0	0.40
Average	106.58	1.65	0.83	120.6	194.0	28.1	0.44
Std. Dev.	0	0	0.10	14.8	5.5	0.8	0.06
600°C, 8" Gage Length							
1BN4881	106.58	1.65	0.76	109.8*	168.4	24.4	0.45*
2			0.87	126.0	154.6	22.4	0.56
3			1.00	144.7	139.0	20.1*	0.72*
4			0.82	118.5	153.9	22.3	0.53
5			0.94	135.7	180.5	26.2*	0.52
6			1.06	153.4*	167.6	24.3	0.63
Average	106.58	1.65	0.91	131.2	161.1	23.3	0.56
Std. Dev.	0	0	0.08	11.4	8.0	1.2	0.05

* Numbers not used in calculating the Average or Standard Deviation.

Table A21

(Continue)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	(percent)
600°C, 10" Gage Length							
1BN48101	106.58	1.65	1.16	168.2	232.1	33.6	0.50
2			0.64	92.6	182.6	26.5	0.35
3			0.66	96.1	165.7	24.0*	0.40
4			1.22	176.6*	267.8	38.8*	0.45
5			0.42	60.5*	185.6	26.9	0.22*
6			0.65	94.6	191.9	27.8	0.34
7			1.13	163.9	188.5	27.3	0.60*
Average	106.58	1.65	0.85	123.1	196.1	28.4	0.41
Std. Dev.	0	0	0.27	39.3	20.4	3.0	0.07
700°C, 8" Gage Length							
2BN4881	106.58	1.65	1.49	215.8*	283.7	41.1*	0.52*
2			1.04	151.0	254.1	36.8	0.41
3			0.65	94.8*	229.4	33.3	0.28*
4			0.86	124.9	236.1	34.2	0.36
5			0.64	92.8*	228.7	33.2	0.28*
6			0.63	91.5*	175.5	25.4*	0.36
7			1.24	179.8	285.2	41.3*	0.44
8			1.06	153.4	264.5	38.3	0.40
9			0.99	143.2	224.6	32.6	0.44
10			1.19	172.3	273.3	39.6	0.44
Average	106.58	1.65	1.06	154.1	244.4	35.4	0.41
Std. Dev.	0	0	0.14	19.9	19.4	2.8	0.04
700°C, 10" Gage Length							
2BN48102	106.58	1.65	0.97	140.0	207.8	30.1	0.47
3			0.78	112.6*	207.3	30.0	0.37*
4			0.95	137.0	217.3	31.5*	0.44
6			0.91	131.8	204.4	29.6	0.44
7			1.03	149.3*	168.8	24.5*	0.61*
8			0.85	123.8	189.9	27.5	0.45
9			0.76	109.8*	159.5	23.1*	0.47
Average	106.58	1.65	0.92	133.2	202.3	29.3	0.45
Std. Dev.	0	0	0.05	7.1	8.4	1.2	0.02

* Numbers not used in calculating the Average or Standard Deviation.

Table A21

(Continued)

Specimen No.	Fiber Area		Tensile Strength		Tensile Modulus		Ultimate Strain (percent)
	(μm^2)	(10^{-7}in^2)	(GPa)	(ksi)	(GPa)	(Msi)	
800°C, 8" Gage Length							
3BN4881A	106.58	1.65	0.73	105.5*	179.3	26.0	0.41*
2			1.22	177.0*	199.4	28.9*	0.61
3			0.99	143.0	188.0	27.2	0.52
4A			1.25	181.6*	155.4	22.5*	0.81*
5			0.74	107.7*	169.8	24.6	0.44
6			1.13	163.9	172.4	25.0	0.66
7A			1.01	145.8	201.2	29.2*	0.50
8			0.76	109.8	151.6	22.0*	0.50
Average	106.58	1.65	1.04	150.9	177.3	25.7	0.54
Std. Dev.	0	0	0.08	11.3	8.1	1.2	0.08
800°C, 10" Gage Length							
3BN48103A	106.58	1.65	1.06	152.9	234.5	34.0*	0.45
4			0.62	89.8*	213.7	31.0	0.29*
5			1.11	161.5	187.3	27.2	0.59
6A			1.03	149.0	197.8	28.7	0.52
7			1.11	161.5	181.3	26.3	0.61
8			0.97	140.0	162.4	23.5*	0.59
9A			1.39	200.7*	213.1	30.9	0.65
Average	106.58	1.65	1.06	153.0	198.6	28.8	0.57
Std. Dev.	0	0	0.06	9.1	14.7	2.1	0.07

* Numbers not used in calculating the Average or Standard Deviation.

Appendix B
Individual Single Fiber Tensile Creep Test Data

Table B1

Individual Single Fiber High Temperature
Tensile Creep Data for Nexel 440, Uncoated

Specimen No.	Test Temperature (°C)	Strain Rate From $\frac{1}{2}$ Hour to 1 Hour (10^{-6} /hour)	Strain Rate From $\frac{1}{2}$ Hour to End of Test (10^{-6} /hour)
DT3501	500	468	51
DT3502		549	85
DT3504		555	20
		<u>524</u>	<u>52</u>
	Average		
	Std. Dev.	49	33
DT3601	600	138	95
DT3602		147	6
DT3606		384	50
		<u>223</u>	<u>50</u>
	Average		
	Std. Dev.	140	44
DT3702	700	1110*	214
DT3704		61	-57*
DT3705		48	165
		<u>54</u>	<u>190</u>
	Average		
	Std. Dev.	9	35
DT3803	800	861	285
DT3808		179	226
DT3809		578	492
		<u>539</u>	<u>334</u>
	Average		
	Std. Dev.	343	140

* Numbers not used in calculating the Average or the Standard Deviation.

Table B2

Individual Single Fiber High Temperature Tensile
Creep Data for Boron-Nitride Coated Nexel 312

Specimen No.	Test Temperature (°C)	Strain Rate From $\frac{1}{2}$ Hour to 1 Hour (10^{-6} /hour)	Strain Rate From $\frac{1}{2}$ Hour to End of Test (10^{-6} /hour)
DT2501	500	778	93
DT2502		483	79
DT2505		279	59
	Average	<u>513</u>	<u>77</u>
	Std. Dev.	251	17
DT2601	600	431	116
DT2602		167	19
DT2604		701	181
DT2605		516	122
	Average	<u>454</u>	<u>110</u>
	Std. Dev.	222	67
DT2702	700	456	136
DT2704		676	159
DT2705		757	188
	Average	<u>630</u>	<u>161</u>
	Std. Dev.	156	26
DT2801	800	344	-19*
DT2803		1010	216
DT2806		583	161
	Average	<u>646</u>	<u>188</u>
	Std. Dev.	338	39

* Numbers not used in calculating the Average or the Standard Deviation.

Table B3

Individual Single Fiber High Temperature Tensile
Creep Data for Boron-Nitride Coated Nexel 440

Specimen No.	Test Temperature (°C)	Strain Rate From $\frac{1}{2}$ Hour to 1 Hour (10^{-6} /hour)	Strain Rate From $\frac{1}{2}$ Hour to End of Test (10^{-6} /hour)
DT4506	500	-74*	39
DT4512		42	45
DT4513		304	-6*
	Average	<u>173</u>	<u>42</u>
	Std. Dev.	185	4
DT4601	600	350	55
DT4603		319	106
DT4604		171	78
	Average	<u>280</u>	<u>80</u>
	Std. Dev.	96	26
DT4701	700	744	146
DT4702		723	133
DT4703		311	34
	Average	<u>593</u>	<u>104</u>
	Std. Dev.	244	61
DT4806	800	209	175
DT4811		35*	-73*
DT4812		659	68
	Average	<u>434</u>	<u>122</u>
	Std. Dev.	318	76

* Numbers not used in calculating the Average or the Standard Deviation.

Table B4

Individual Single Fiber High Temperature Tensile
Creep Data for Boron-Nitride Coated Nexel 480

Specimen No.	Test Temperature (°C)	Strain Rate From $\frac{1}{2}$ Hour to 1 Hour (10^{-6} /hour)	Strain Rate From $\frac{1}{2}$ Hour to End of Test (10^{-6} /hour)
DT5503	500	38	17
DT5504		601	118
DT5506		197	23
	Average	<u>279</u>	<u>53</u>
	Std. Dev.	290	56
DT5601	600	315	104
DT5602		165	16
DT5604		250	60
DT5605		391	-7*
	Average	<u>280</u>	<u>60</u>
	Std. Dev.	96	44
DT5701	700	118	28
DT5703		293	129
DT5705		-107*	32
	Average	<u>206</u>	<u>63</u>
	Std. Dev.	124	57
DT5801	800	405	91
DT5804		509	-105*
DT5805		398	-43*
DT5806		37*	-49*
	Average	<u>437</u>	<u>91</u>
	Std. Dev.	62	-

* Numbers not used in calculating the Average or the Standard Deviation.

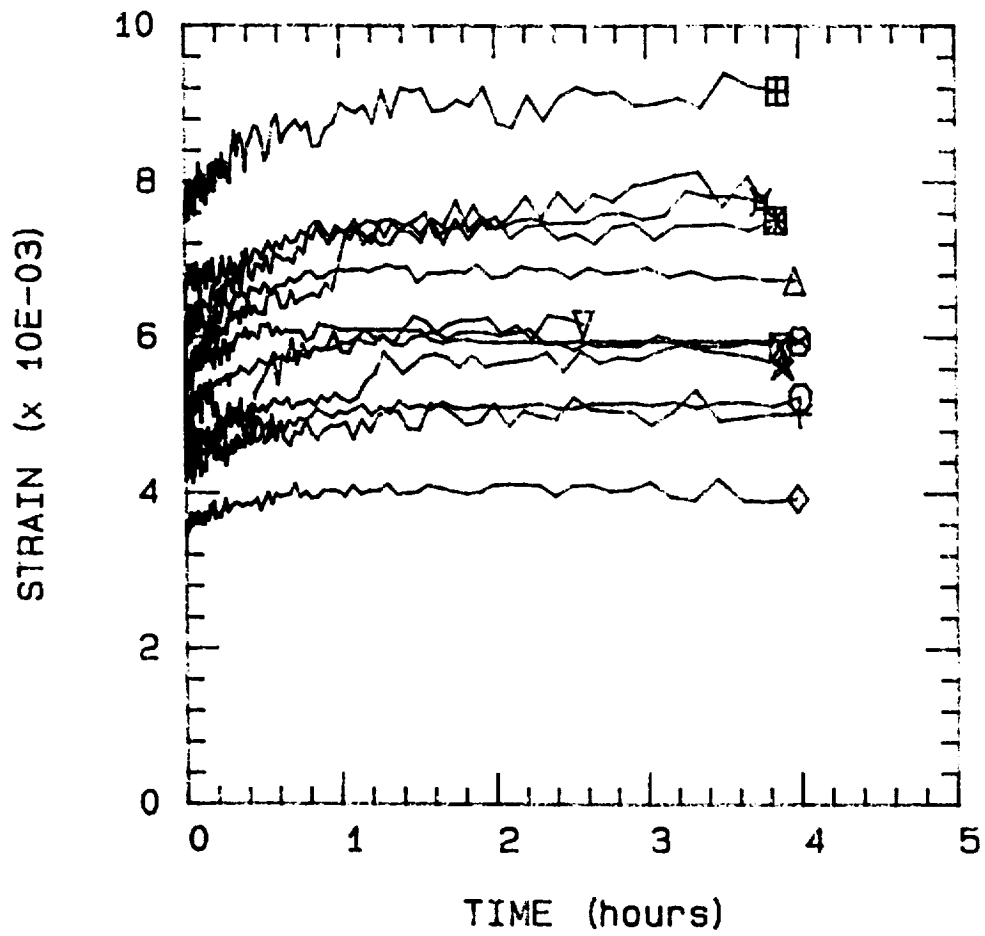
Table B5

Individual Single Fiber High Temperature Tensile
Creep Data for Boron-Nitride Coated Nicalon NLM-102

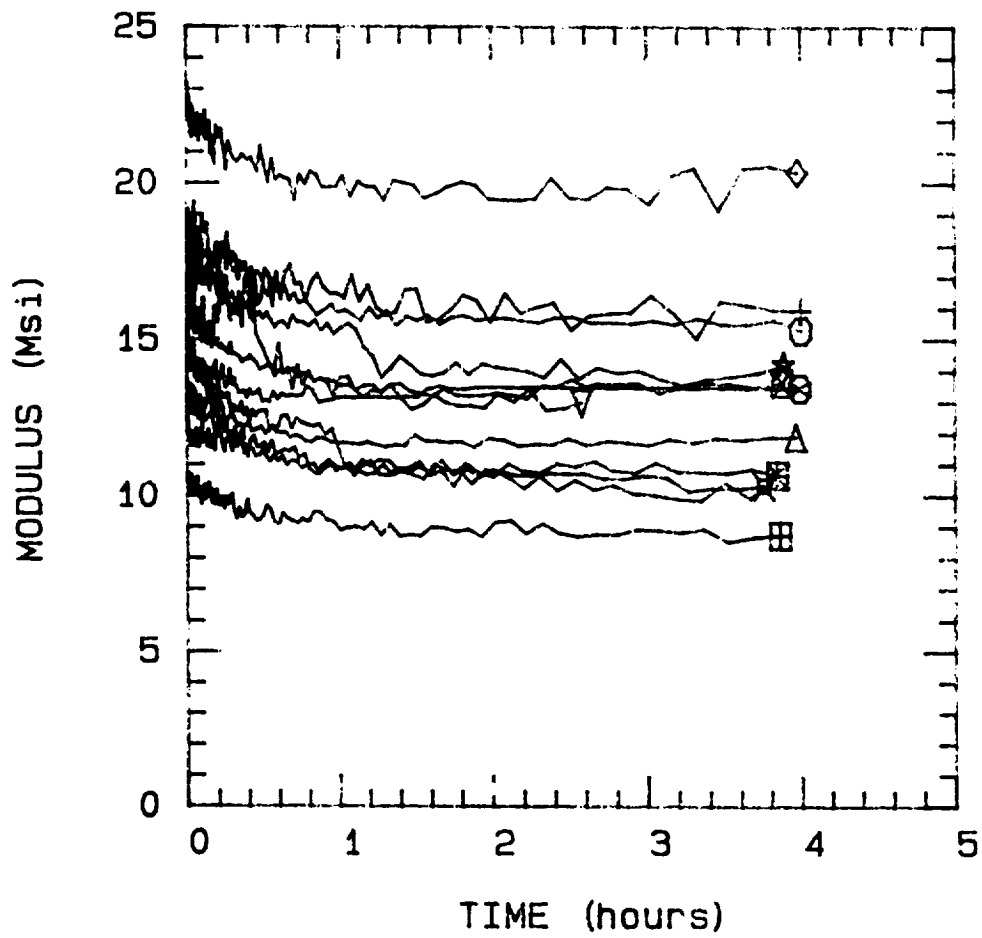
Specimen No.	Test Temperature (°C)	Strain Rate From $\frac{1}{2}$ Hour to 1 Hour (10^{-6} /hour)	Strain Rate From $\frac{1}{2}$ Hour to End of Test (10^{-6} /hour)
DT1507	500	1150	298
DT1508		606	172
DT1510		-198*	-14*
		Average	878
		Std. Dev.	385
DT1602	600	1390*	291
DT1603		698	-90*
DT1605		289	13*
DT1607		587	156
		Average	525
		Std. Dev.	212
DT1702	700	303	84
DT1703		468	47
DT1706		570	143
		Average	447
		Std. Dev.	135
DT1801	800	475	73
DT1802		-18*	-1*
DT1803		-427*	155
		Average	475
		Std. Dev.	-

* Numbers not used in calculating the Average or the Standard Deviation.

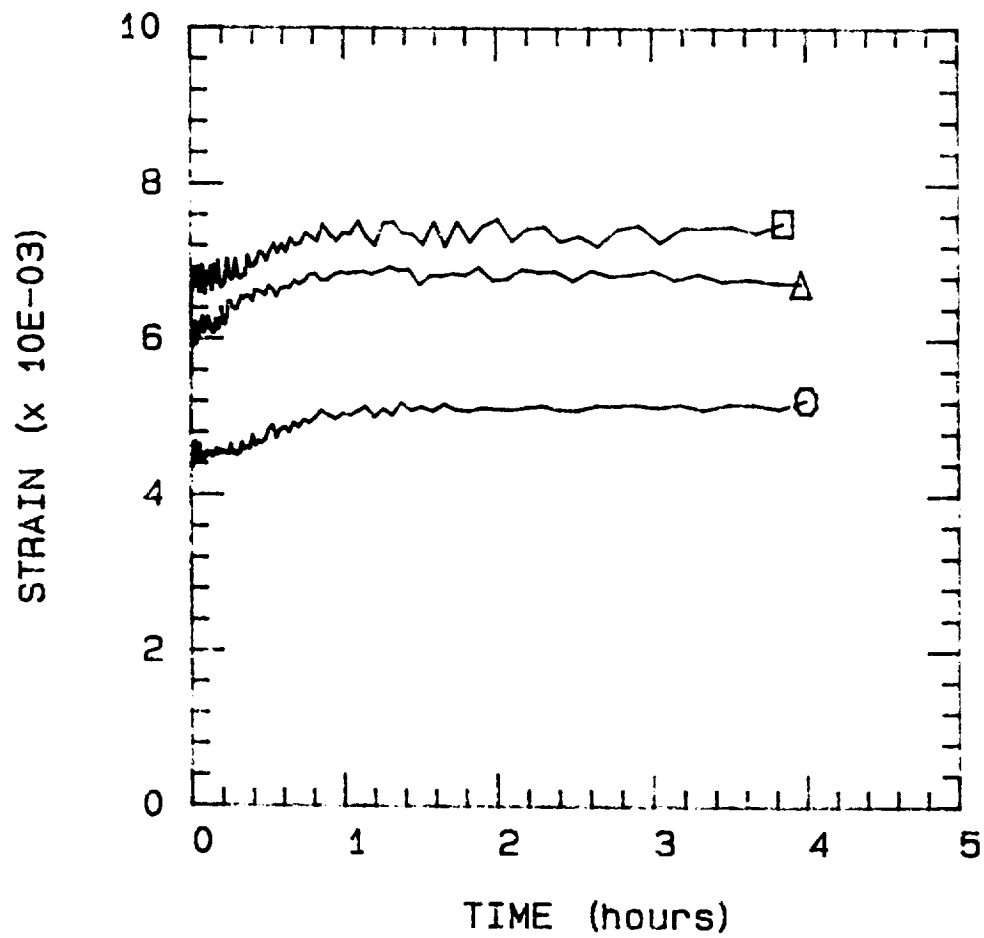
NEXTEL 440



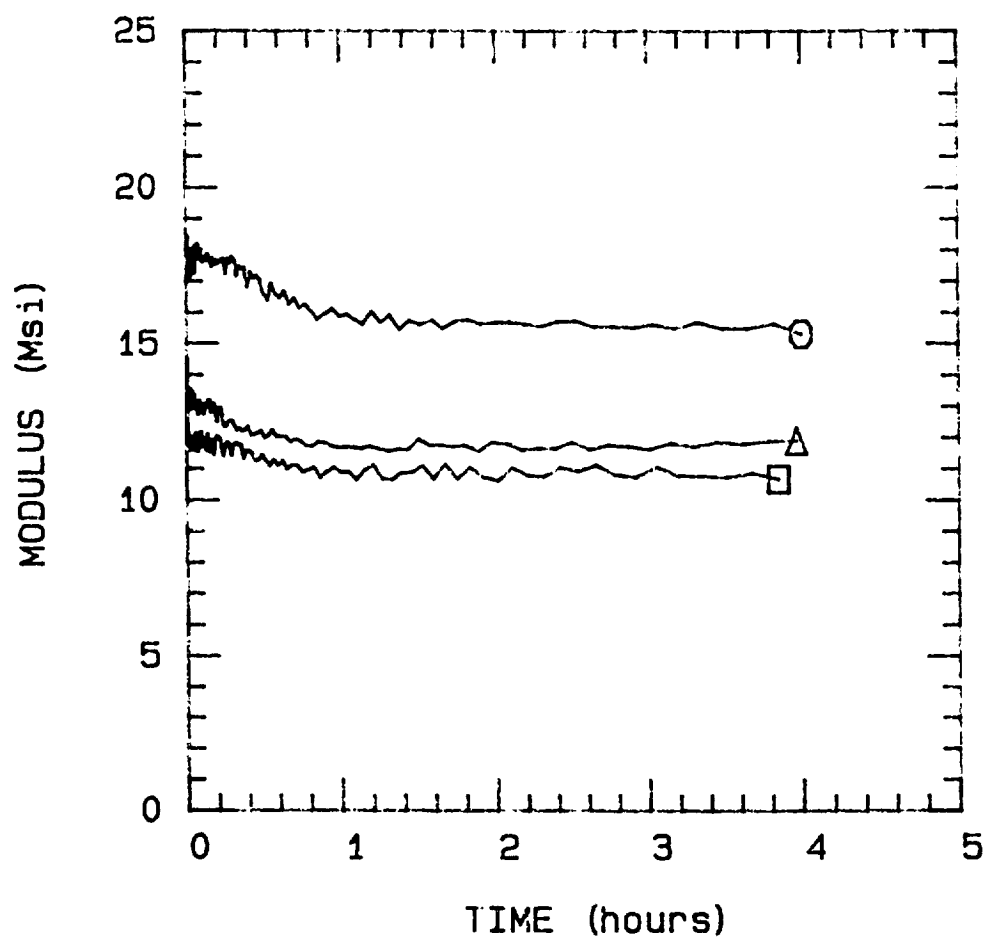
NEXTEL 440



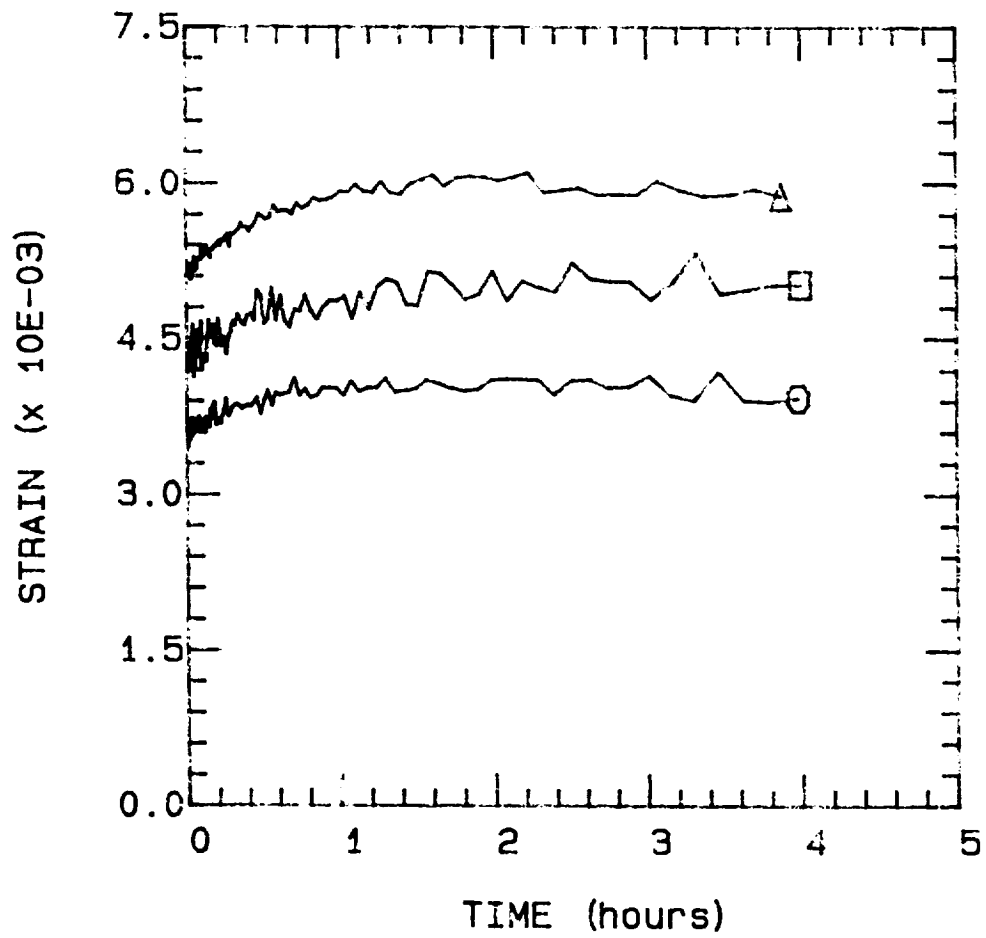
NEXTEL 440 500 DEG C



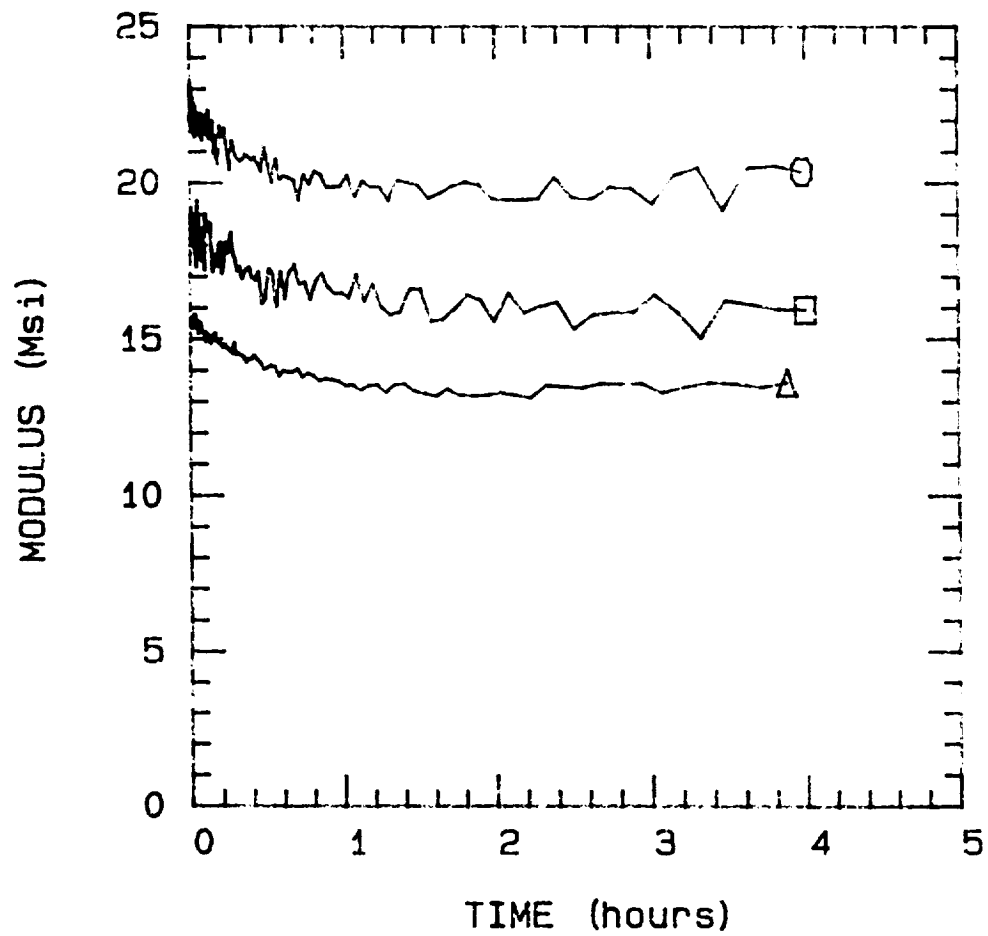
NEXTEL 440 500 DEG C



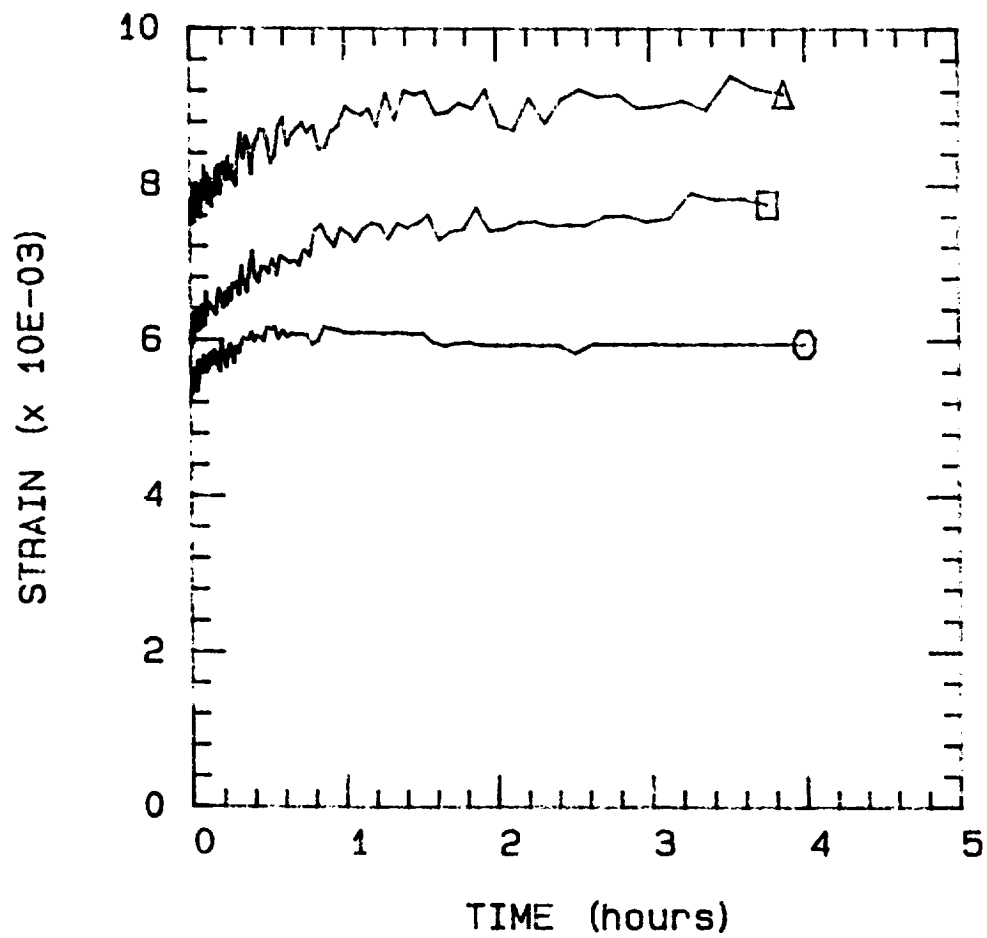
NEXTEL 440 600 DEG C



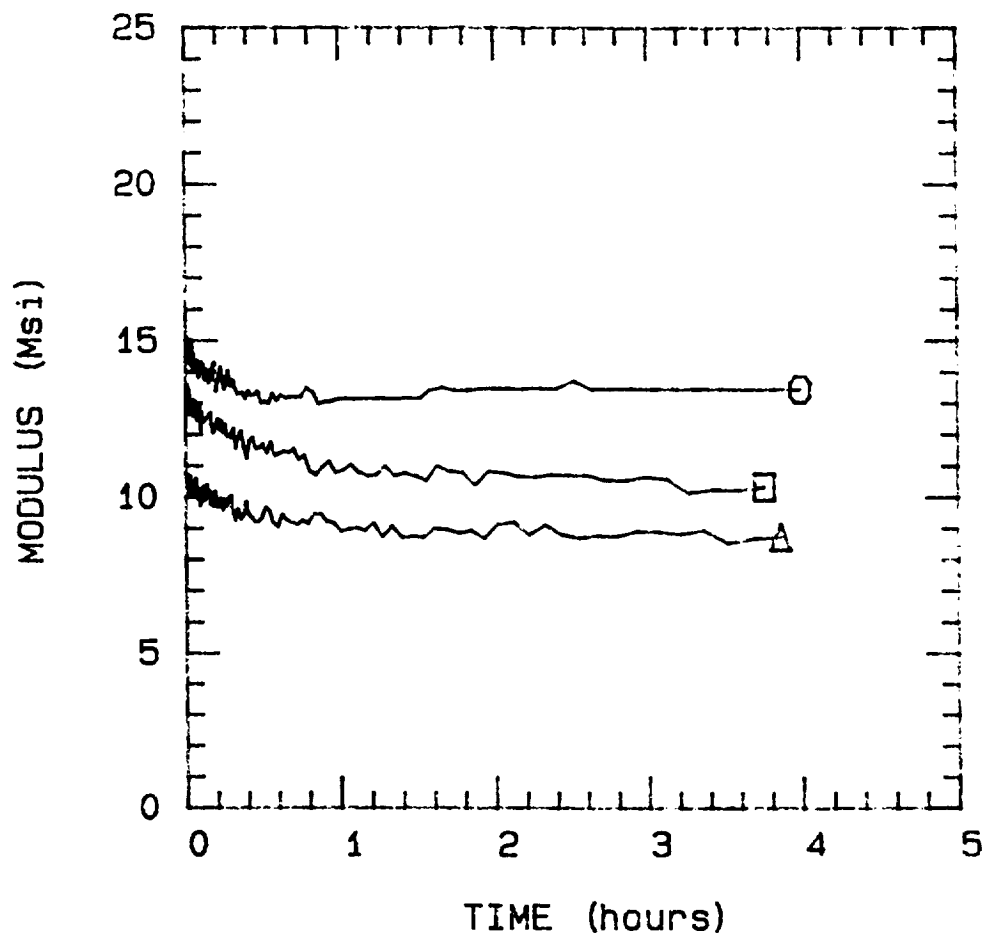
NEXTEL 440 600 DEG C



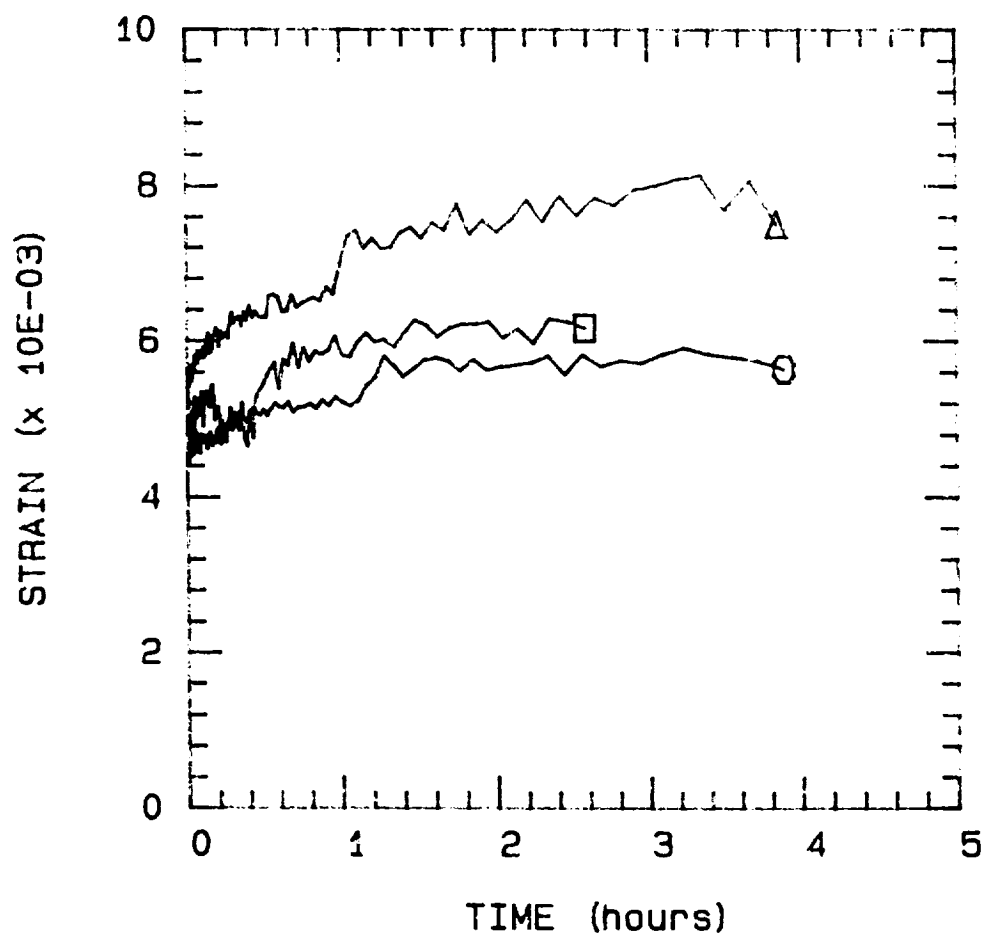
NEXTEL 440 700 DEG C



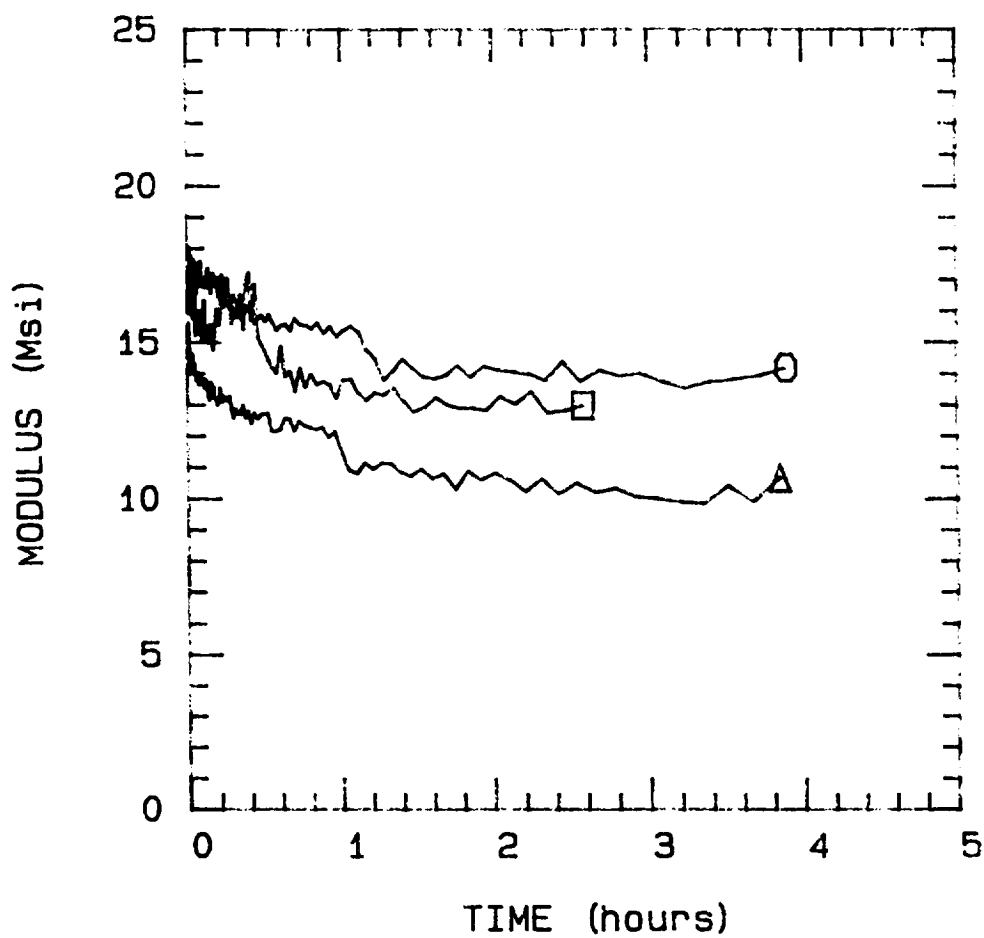
NEXTEL 440 700 DEG C



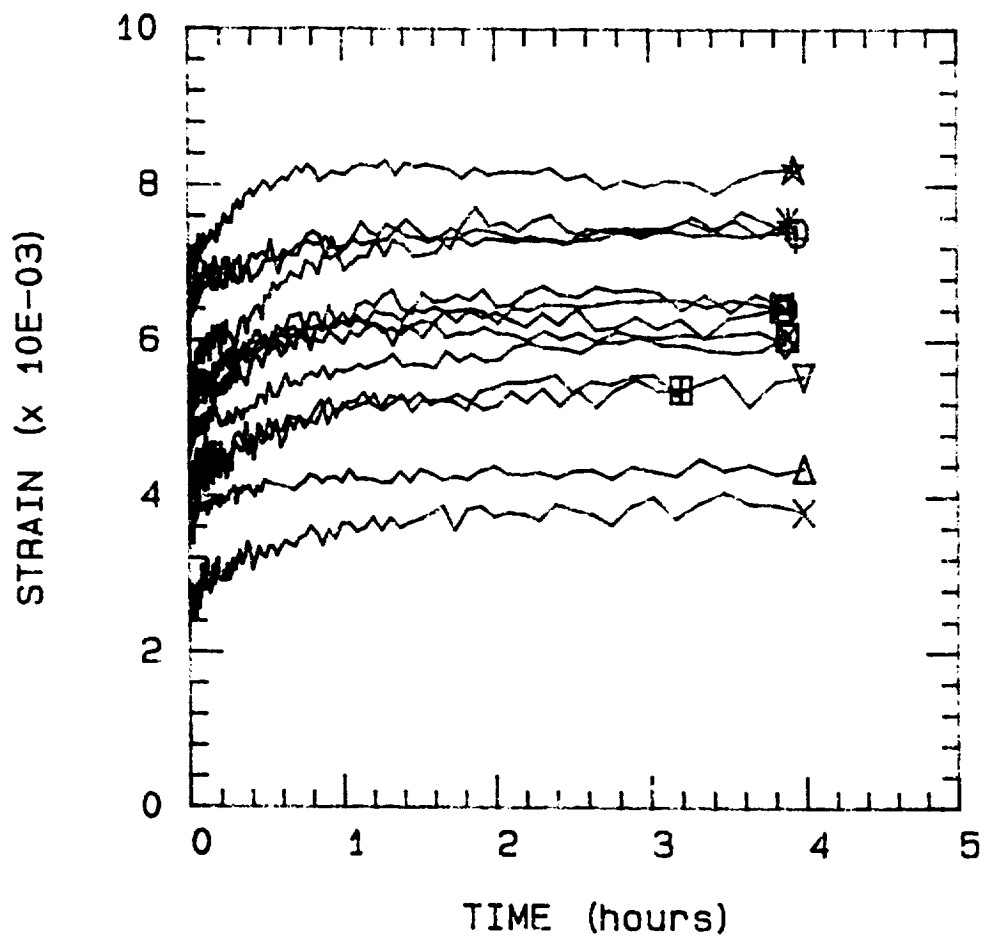
NEXTEL 440 800 DEG C



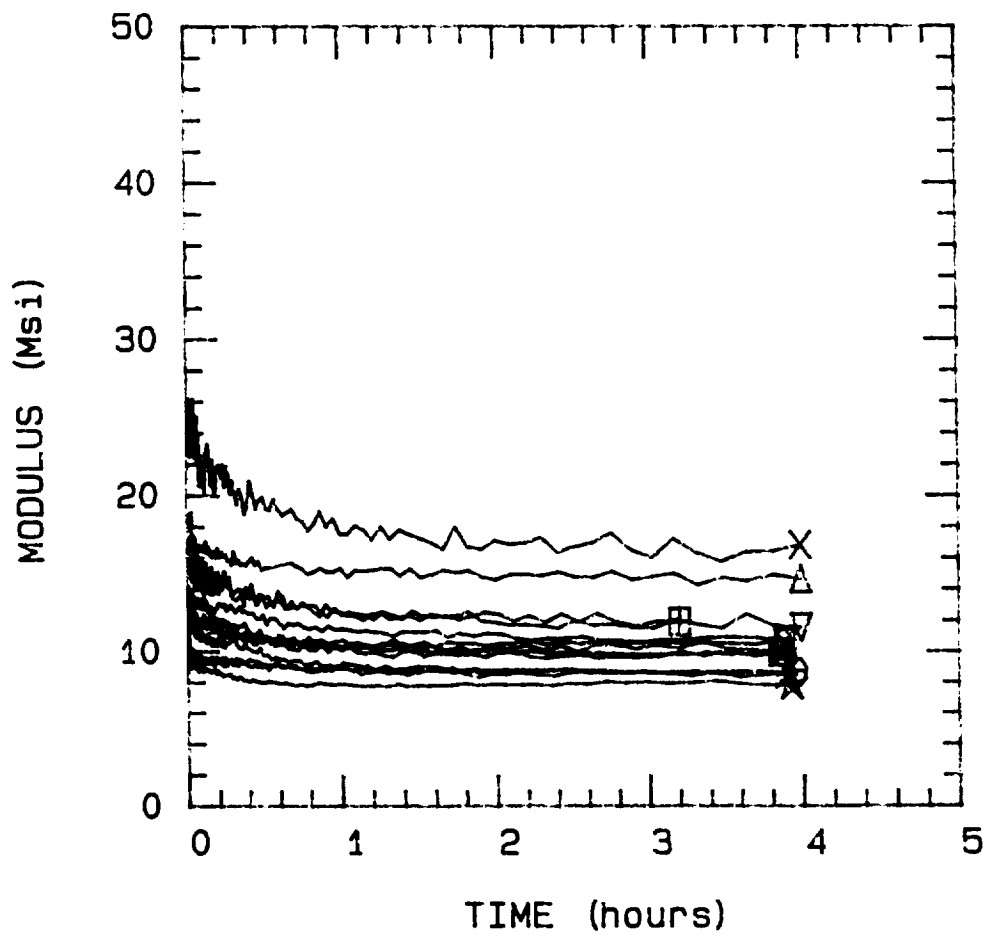
NEXTEL 440 800 DEG C



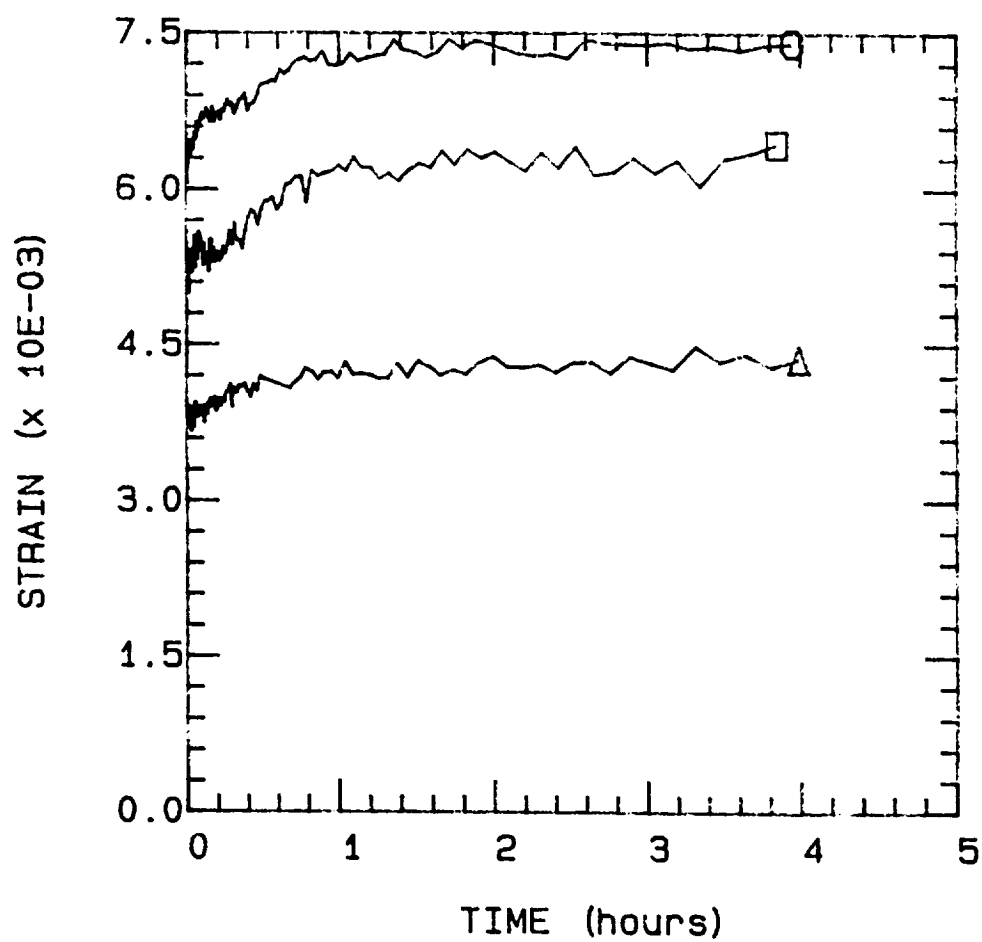
NEXTEL BN312



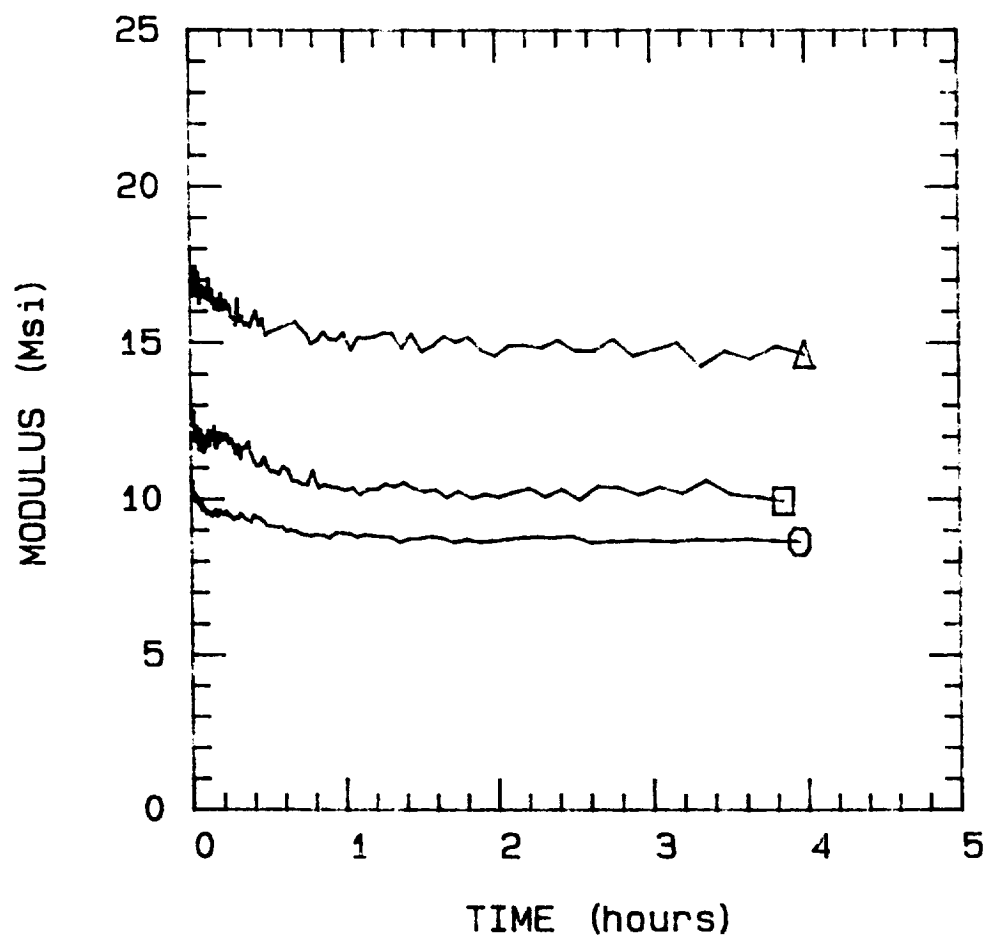
NEXTEL BN312



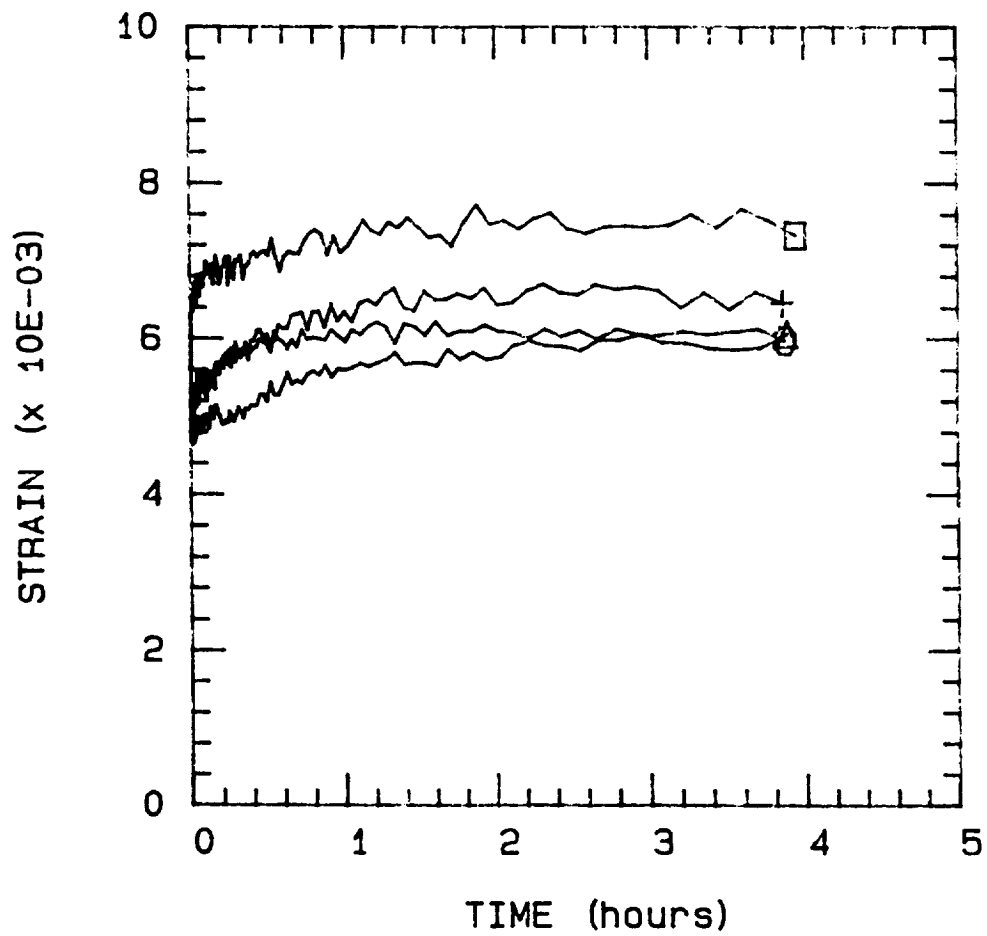
NEXTEL BN312 500 DEG C



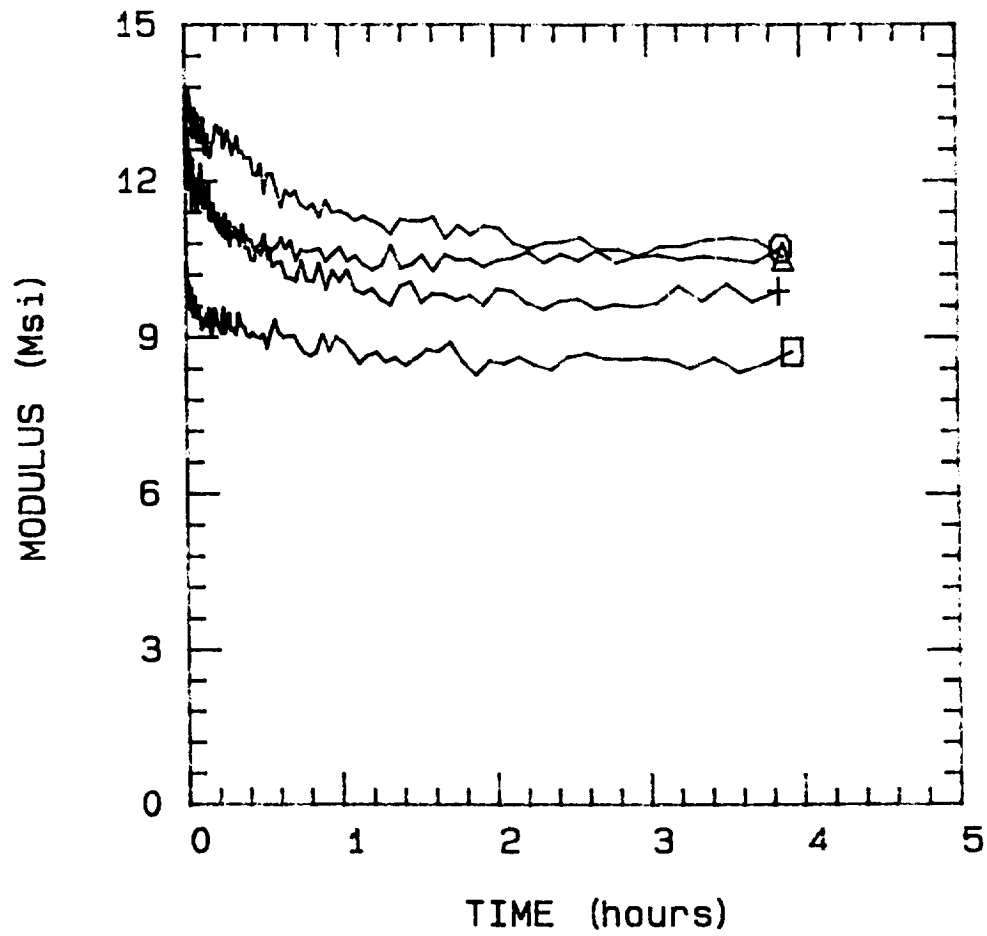
NEXTEL BN312 500 DEG C



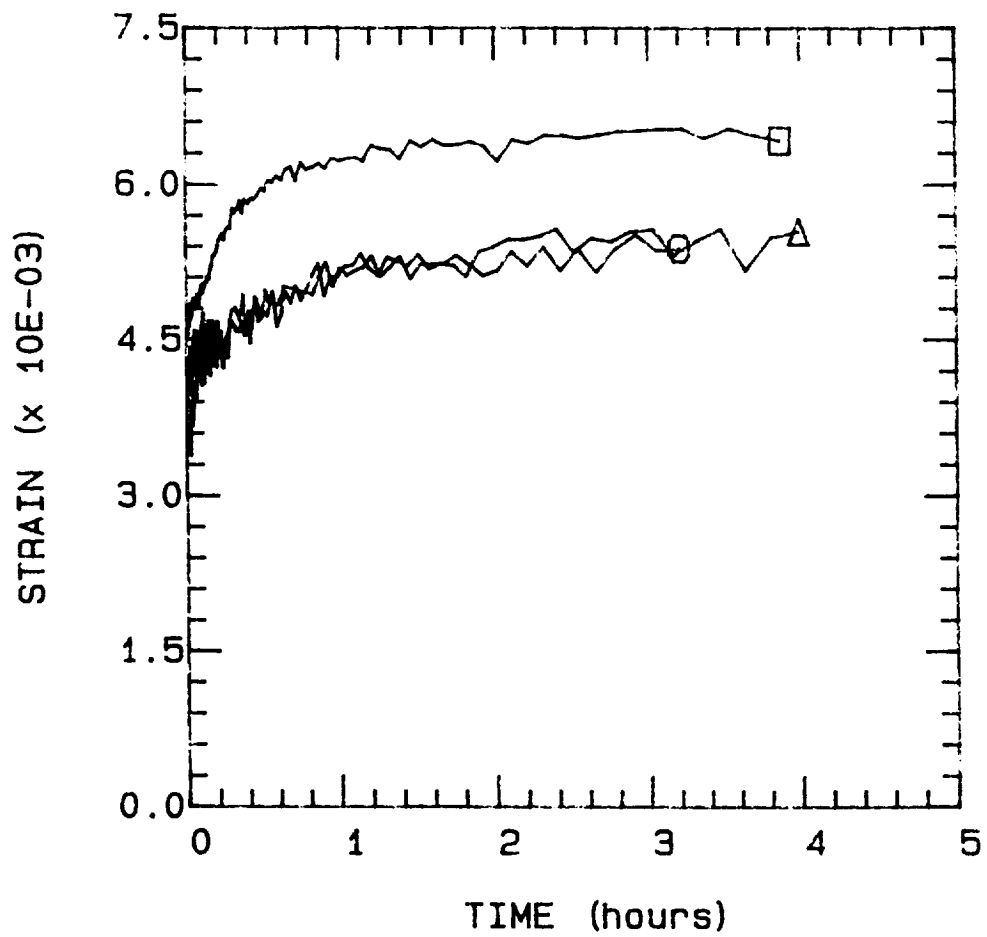
NEXTEL BN312 600 DEG C



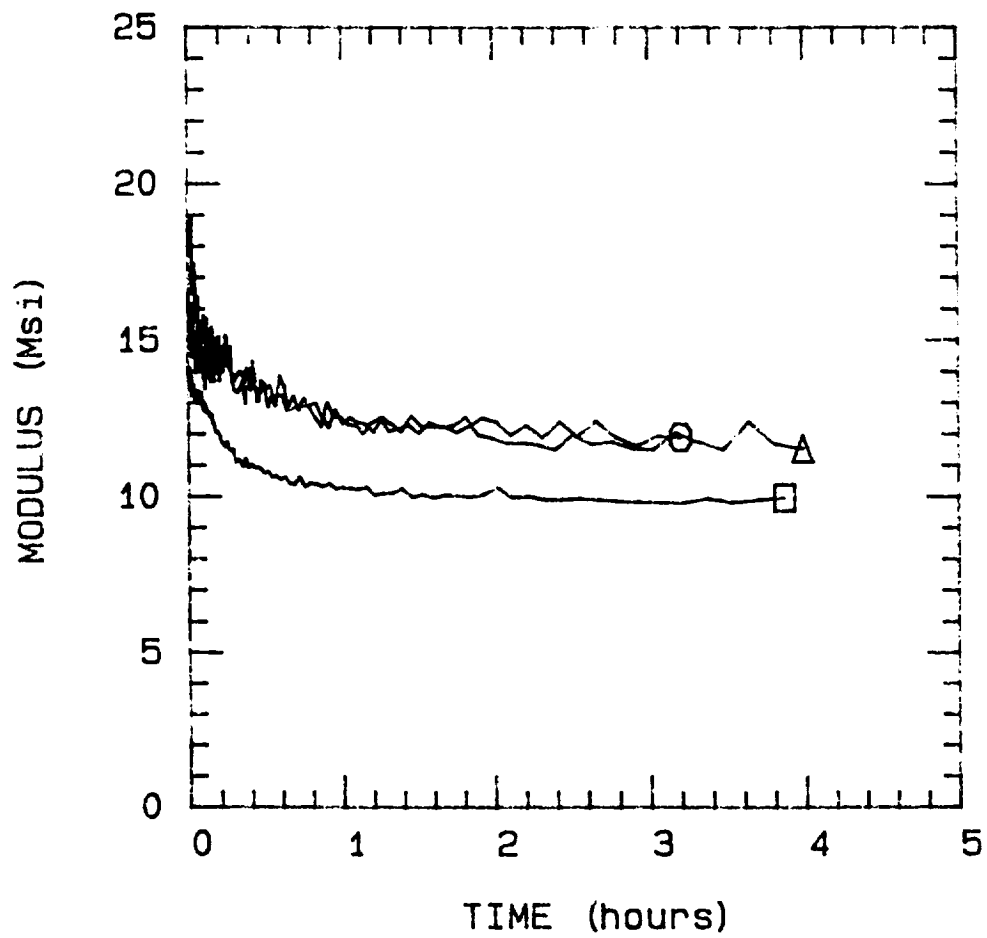
NEXTEL BN312 600 DEG C



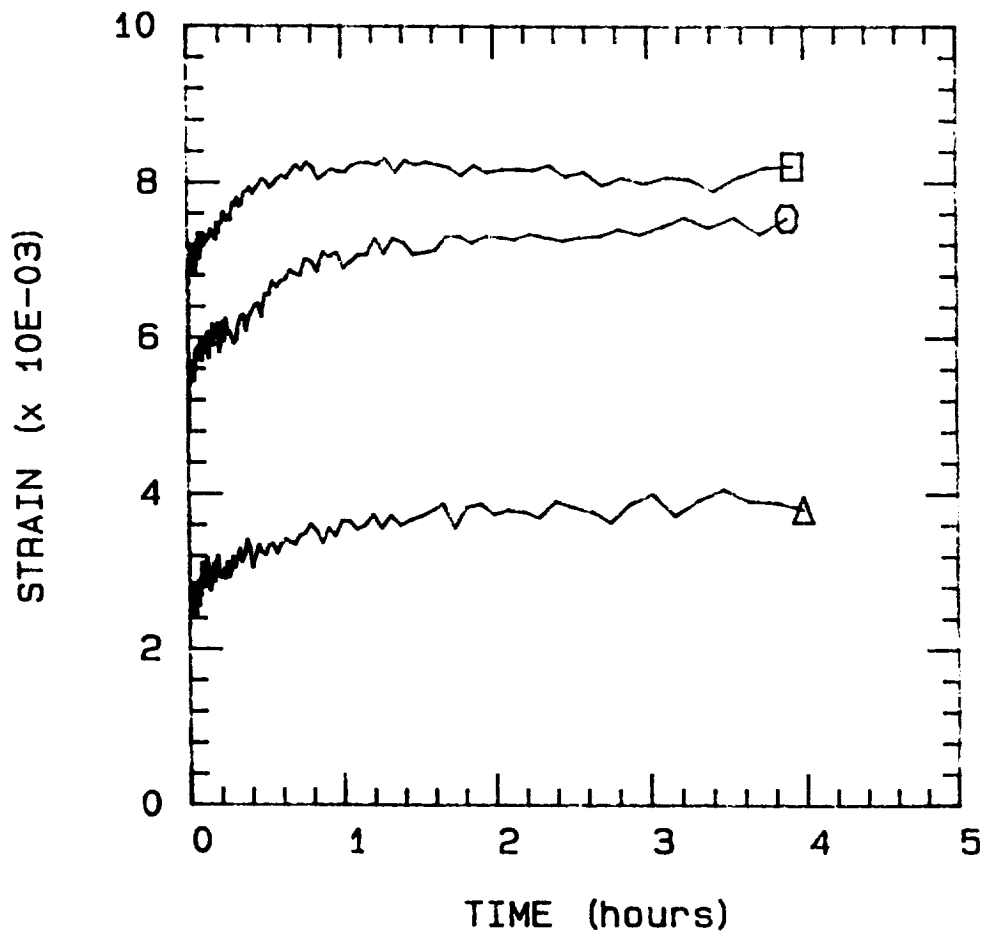
NEXTEL BN312 700 DEG C



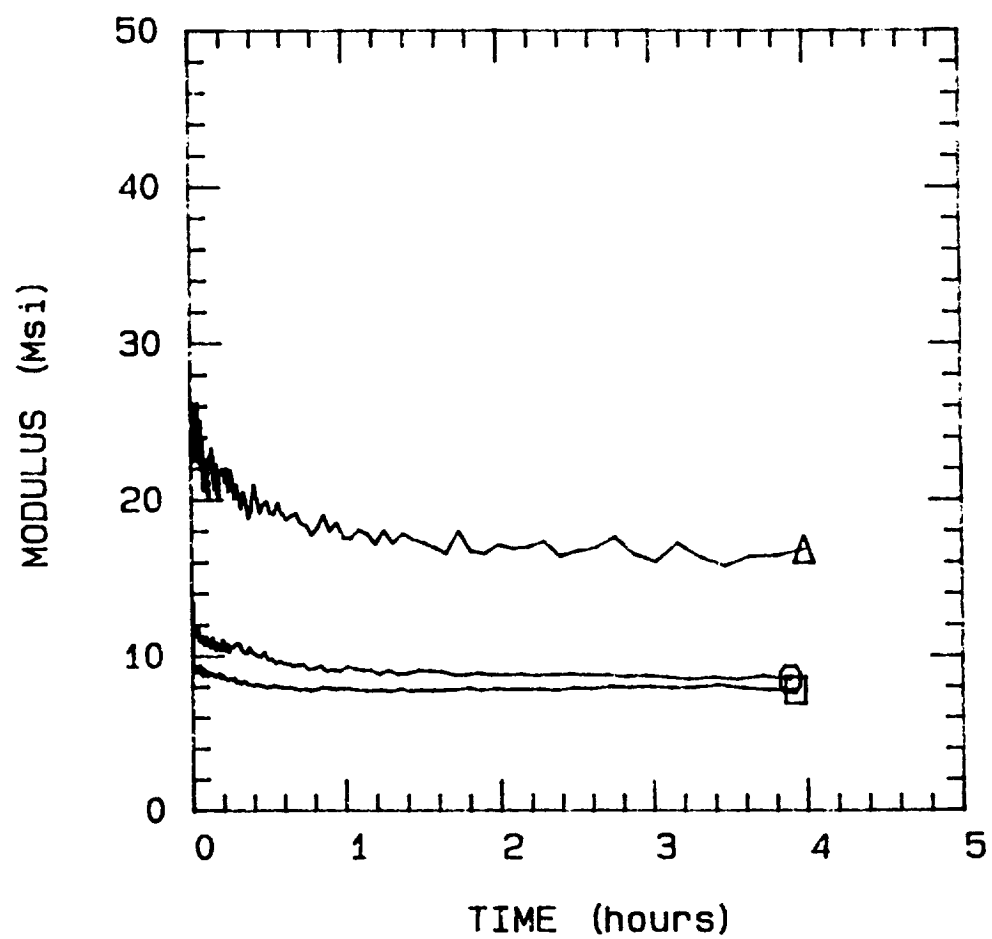
NEXTEL BN312 700 DEG C



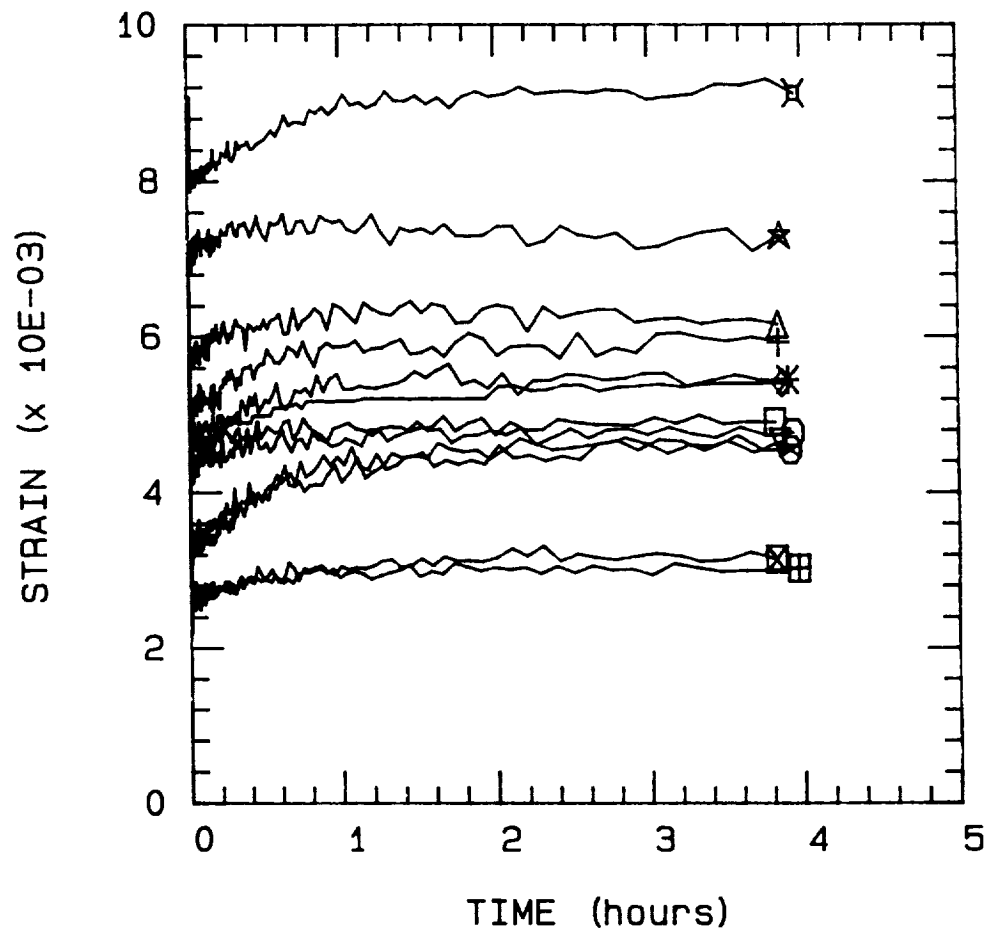
NEXTEL BN312 800 DEG C



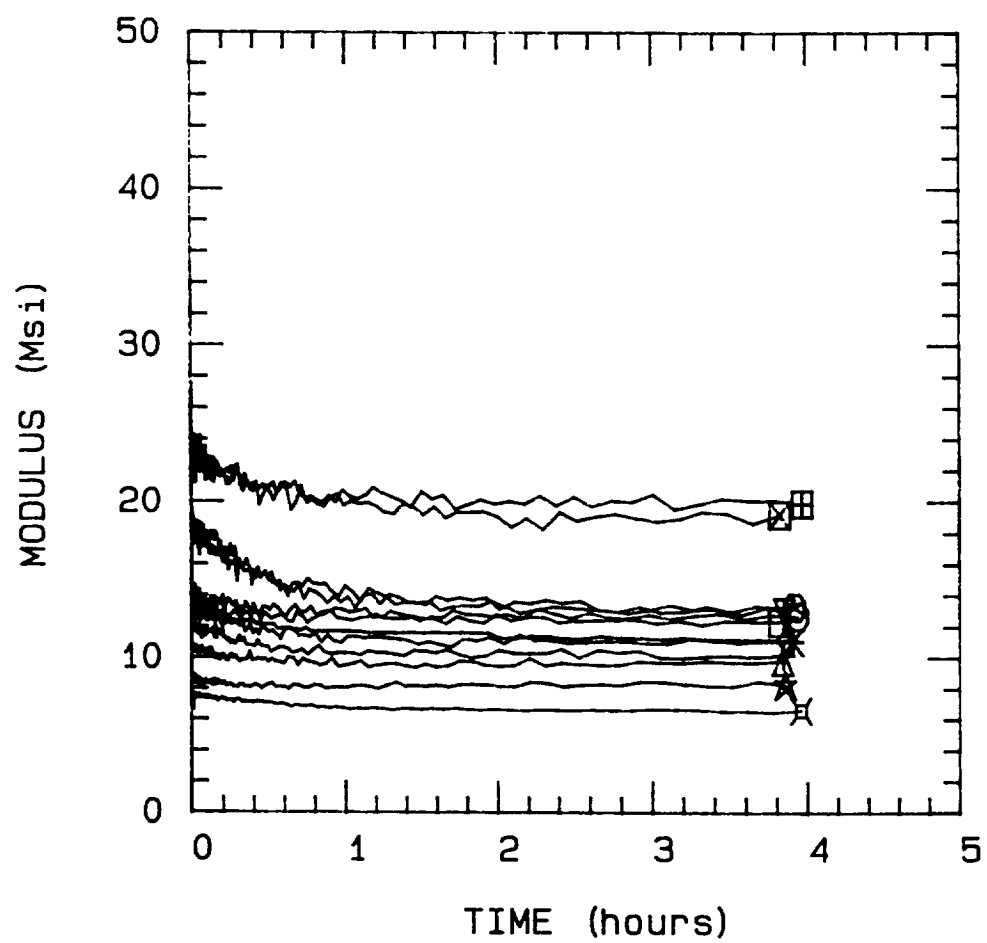
NEXTEL BN312 800 DEG C



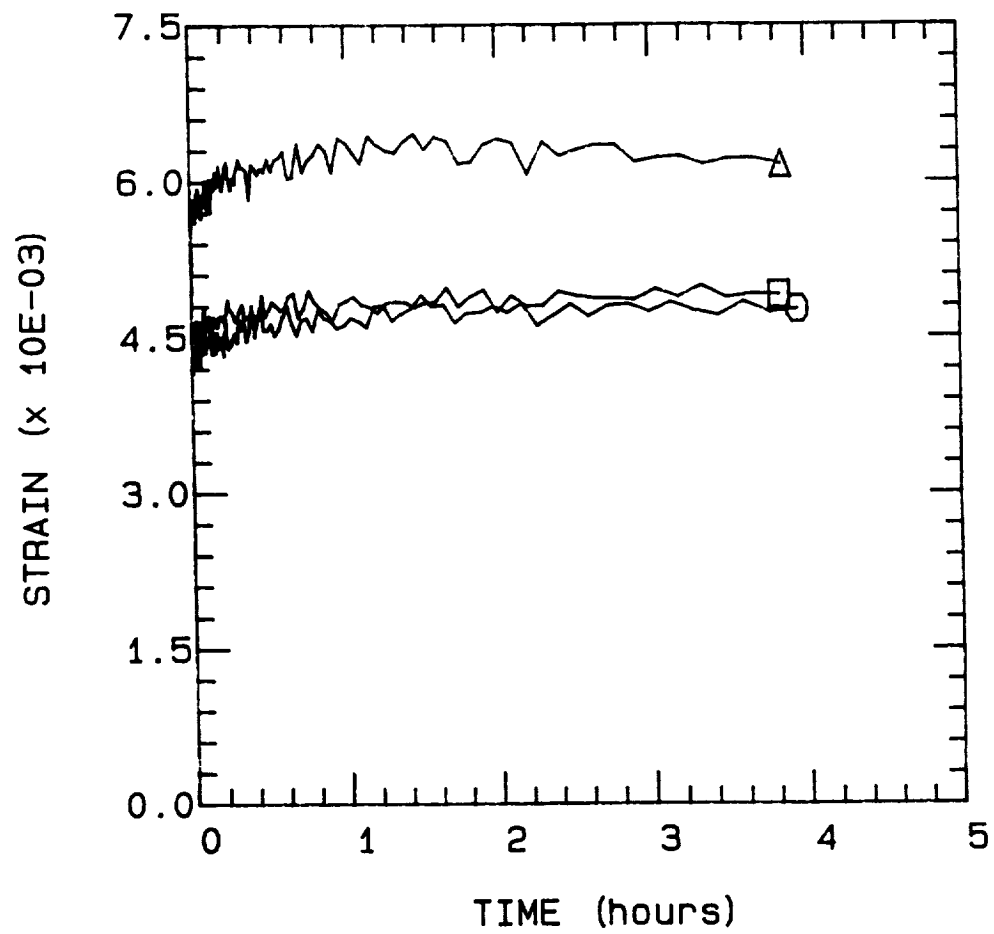
NEXTEL BN440



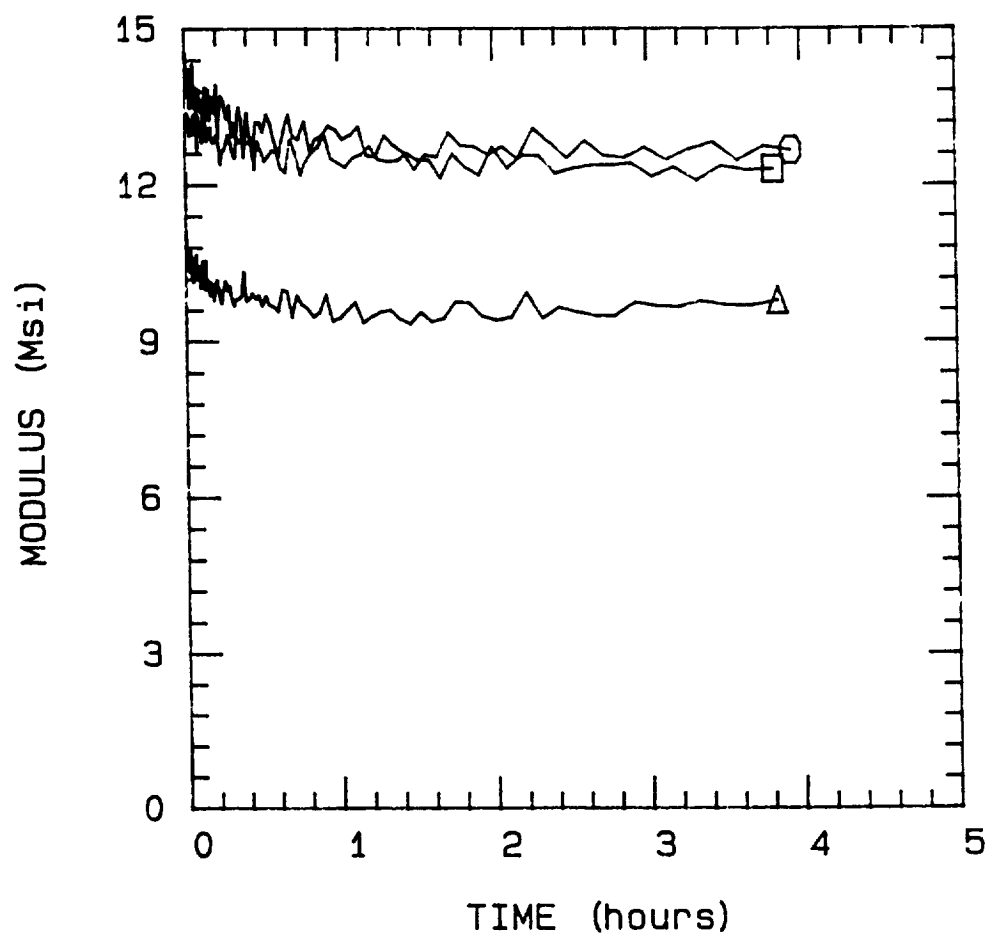
NEXTEL BN440



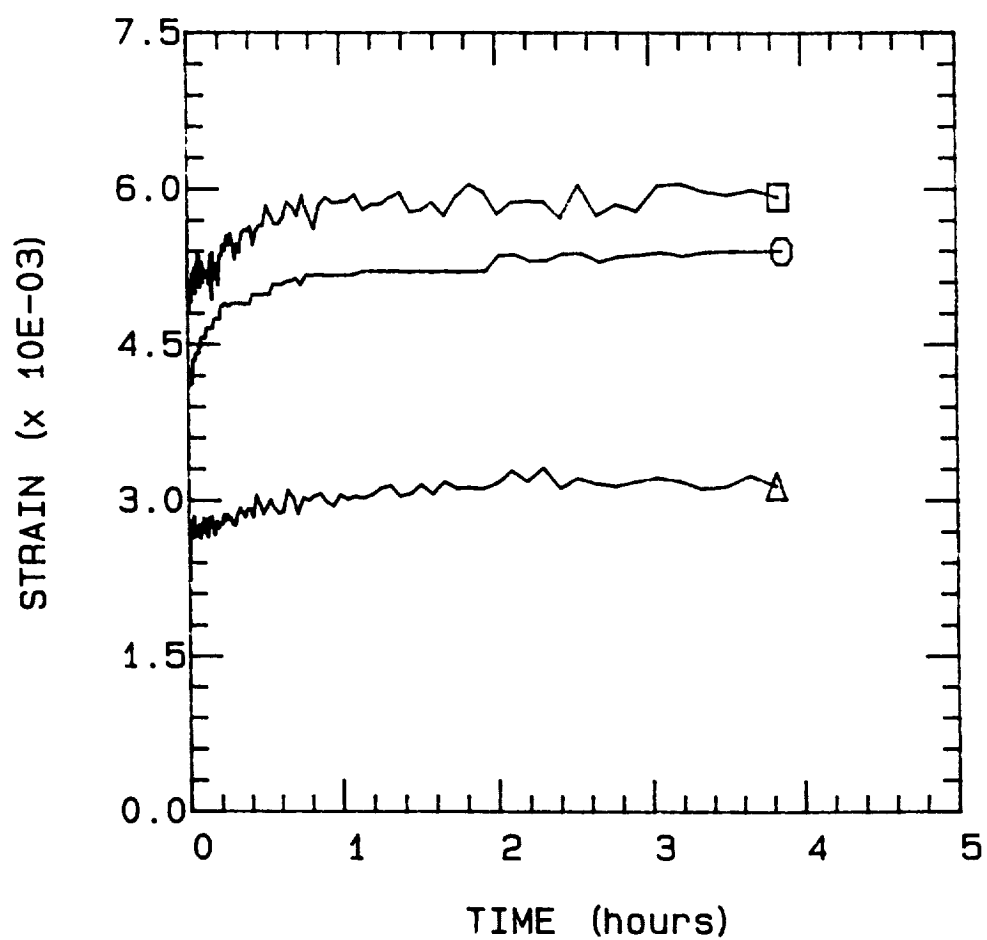
NEXTEL BN440 500 DEG C



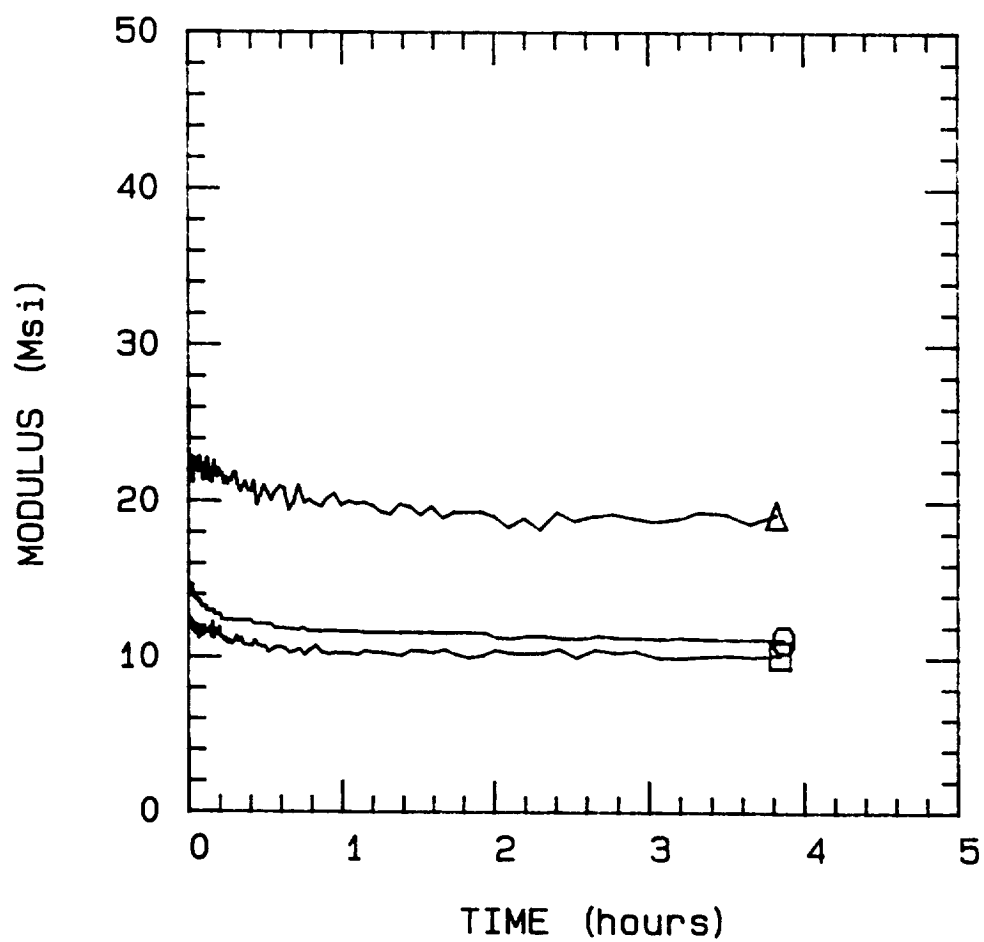
NEXTEL BN440 500 DEG C



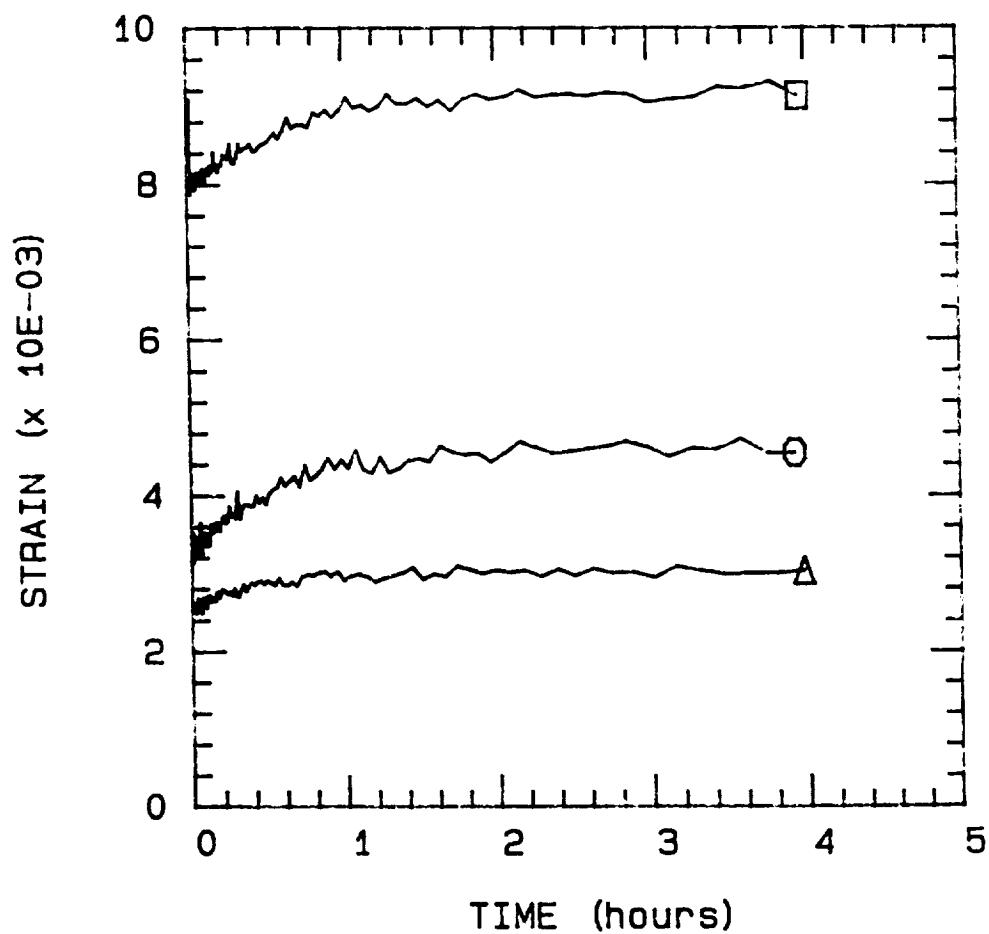
NEXTEL BN440 600 DEG C



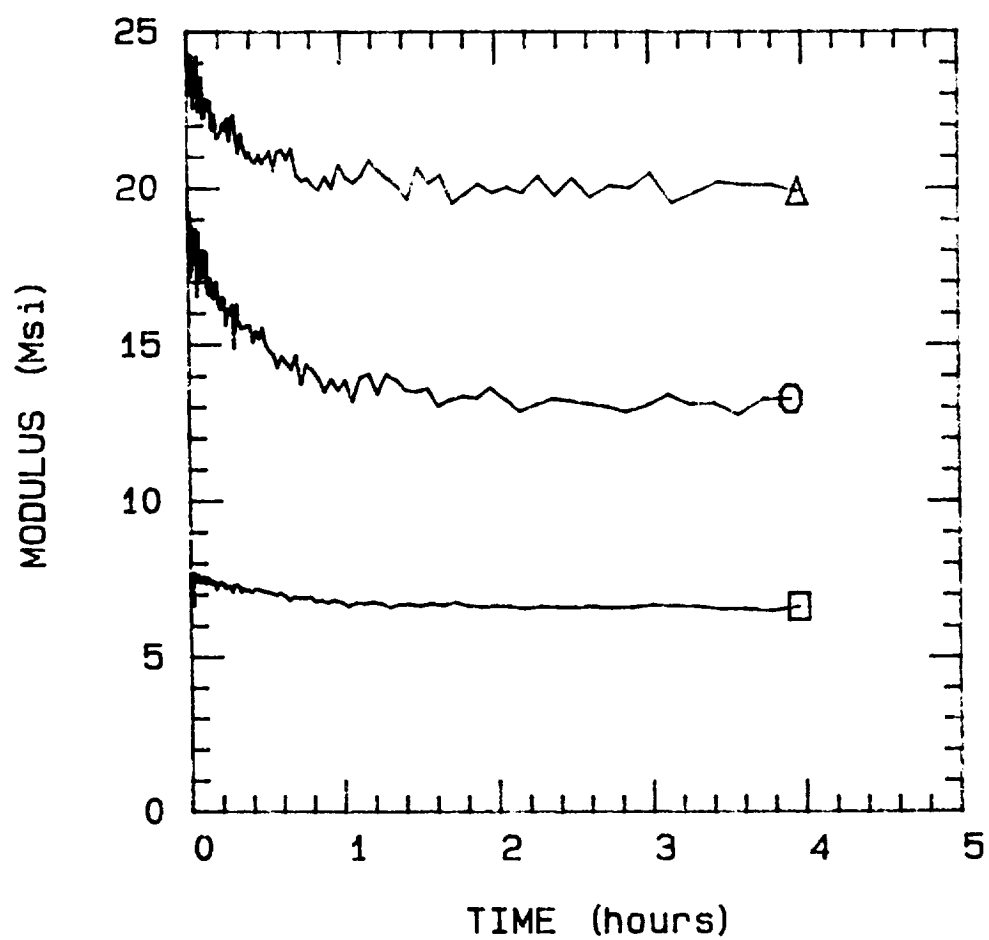
NEXTEL BN440 600 DEG C



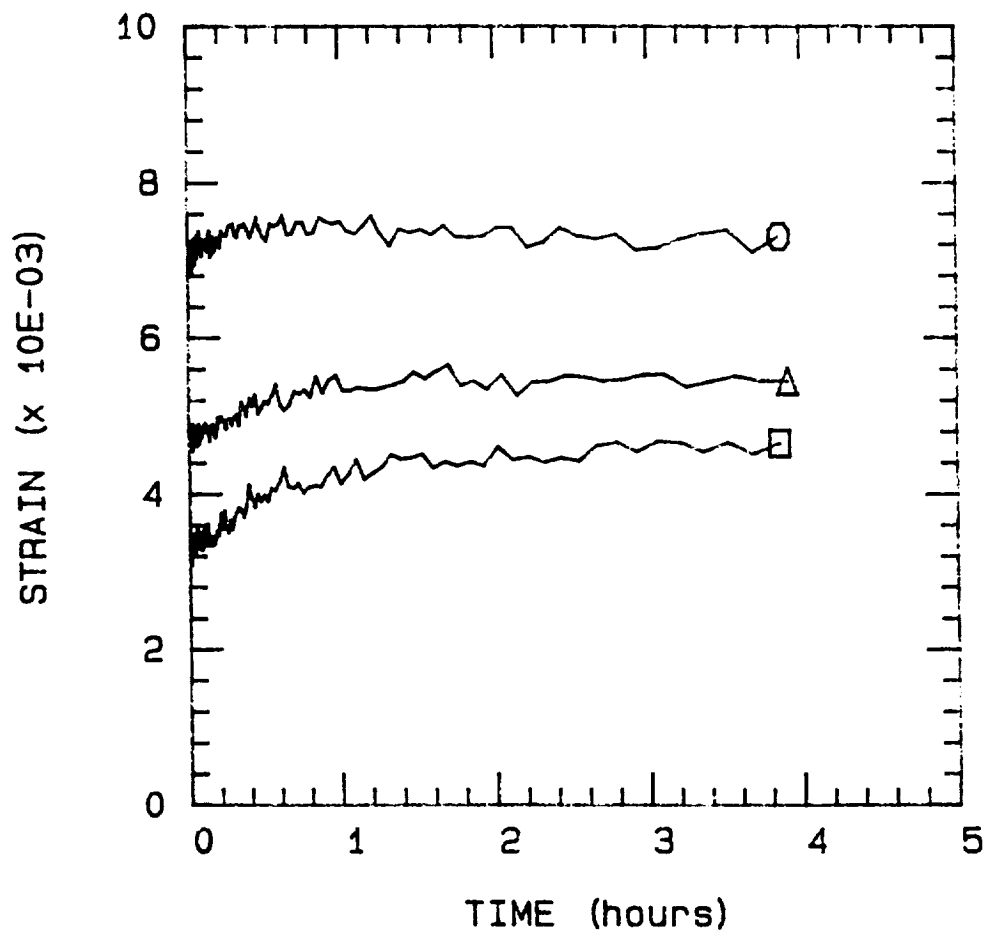
NEXTEL BN440 700 DEG C



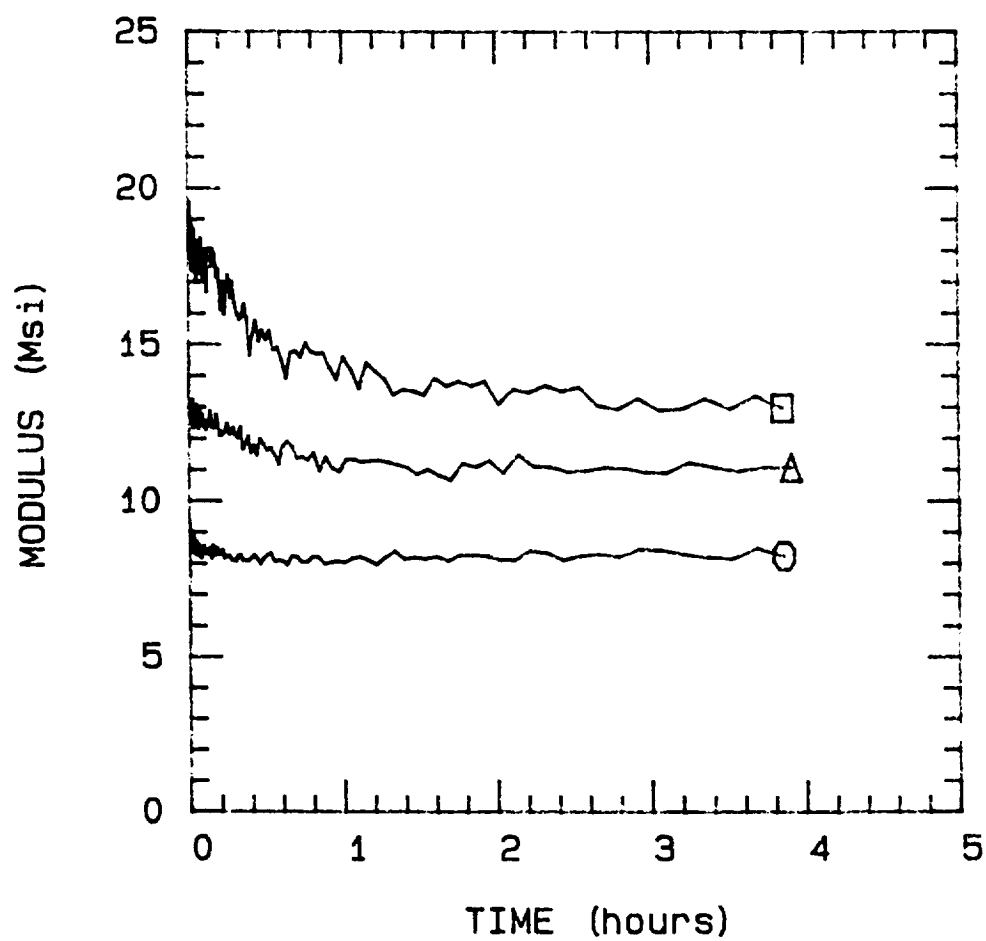
NEXTEL BN440 700 DEG C



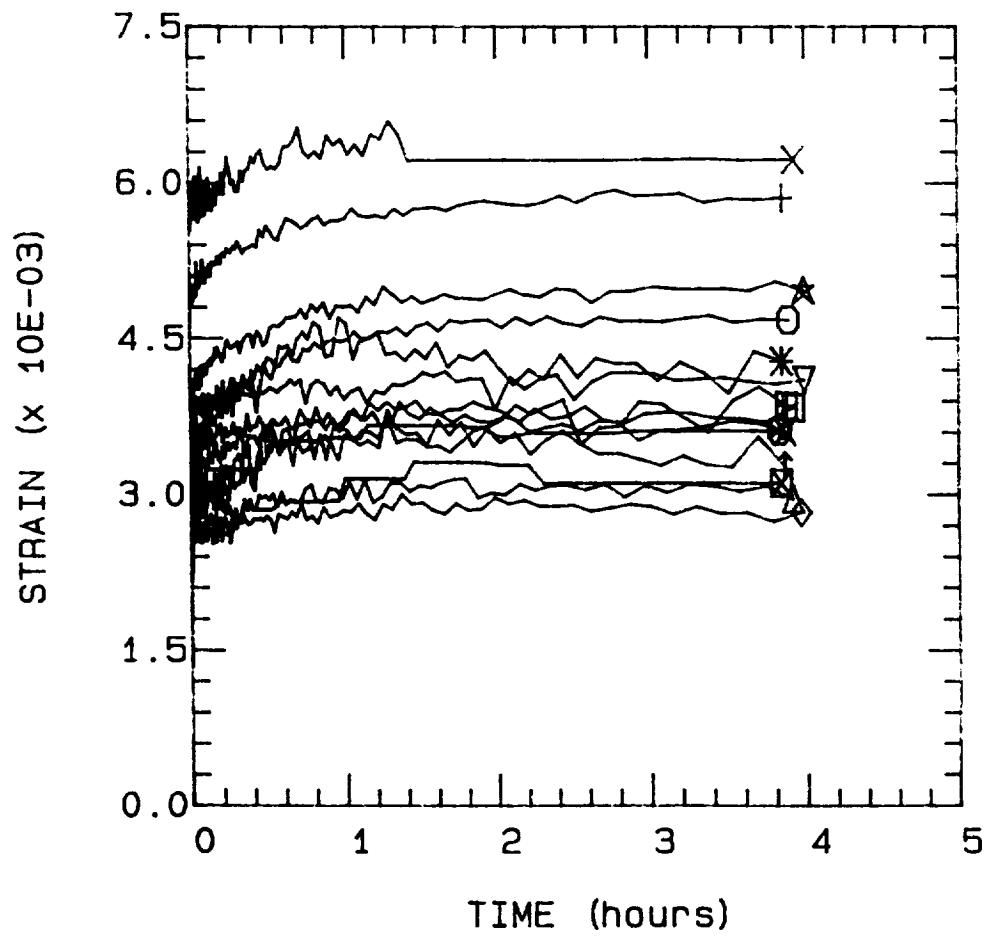
NEXTEL BN440 800 DEG C



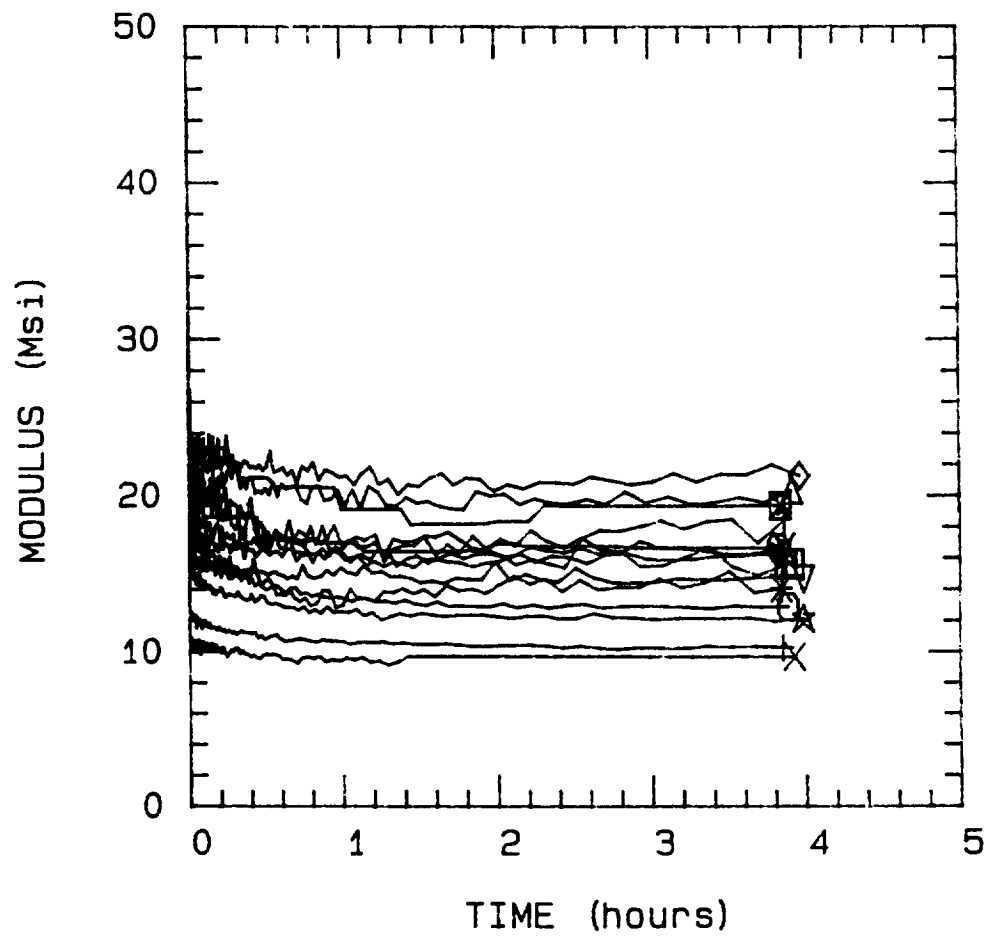
NEXTEL BN440 800 DEG C



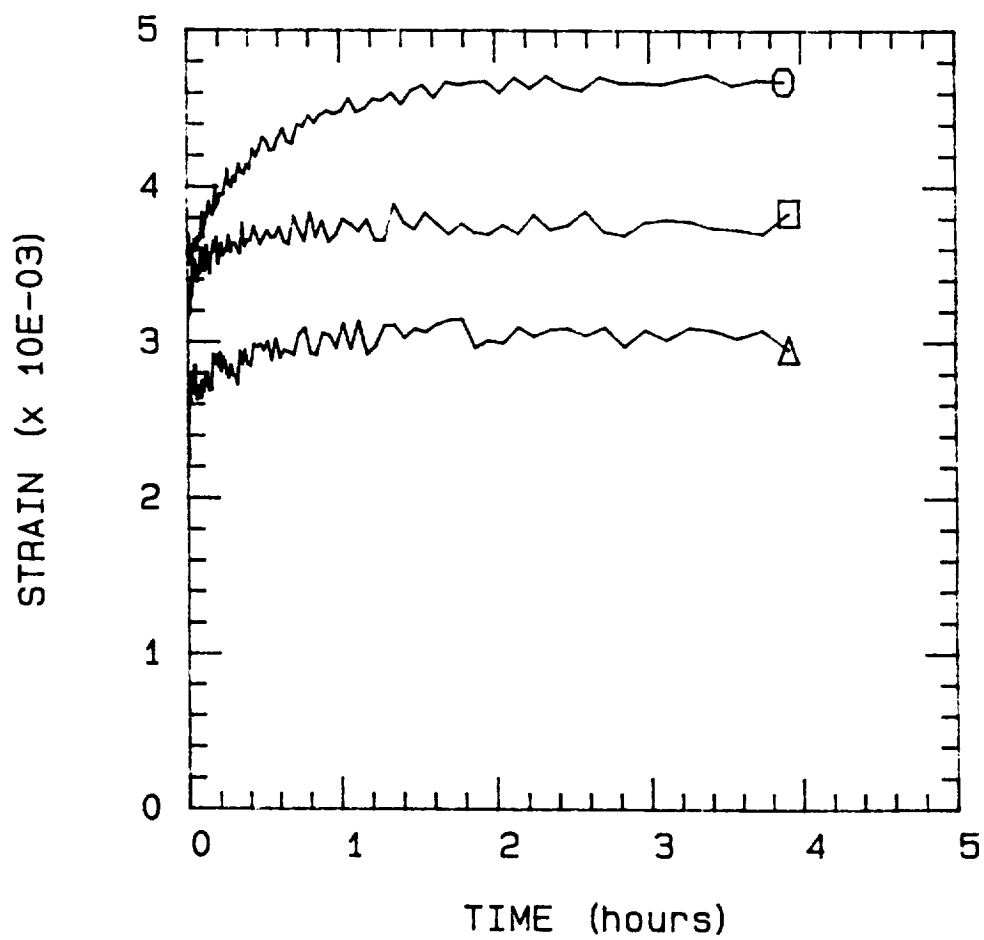
NEXTEL BN480



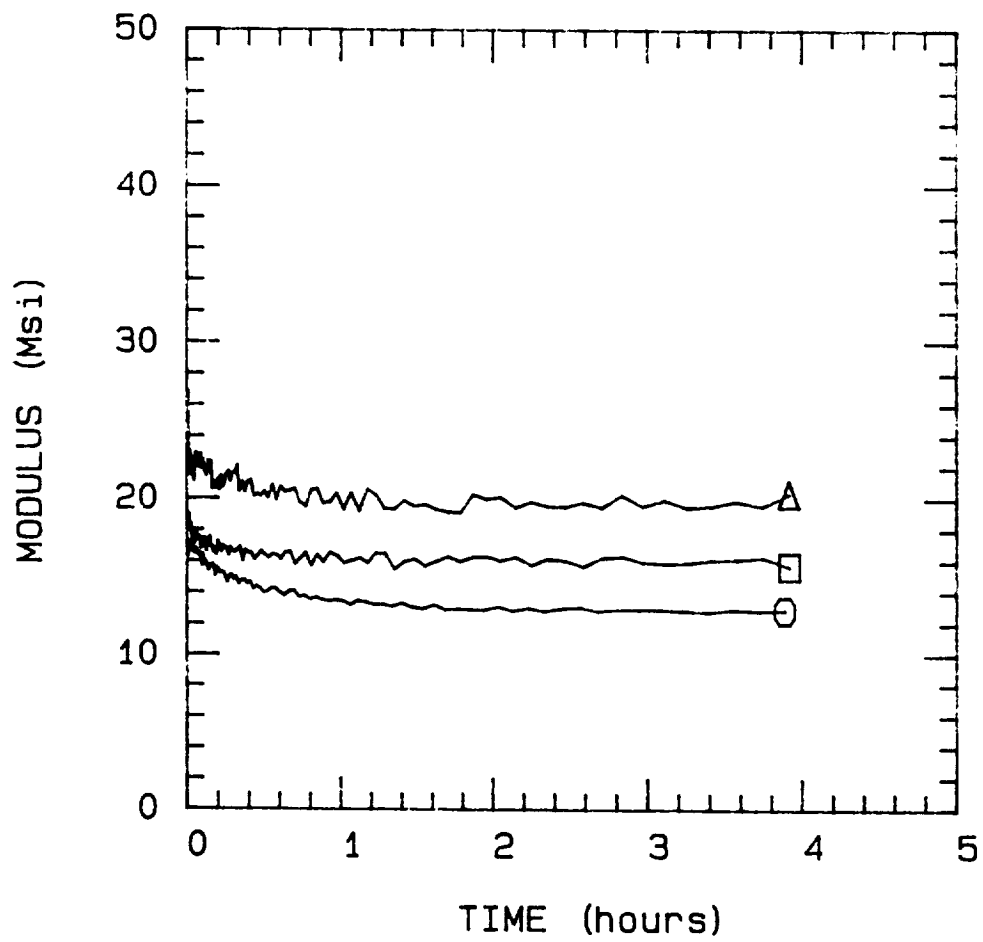
NEXTEL BN480



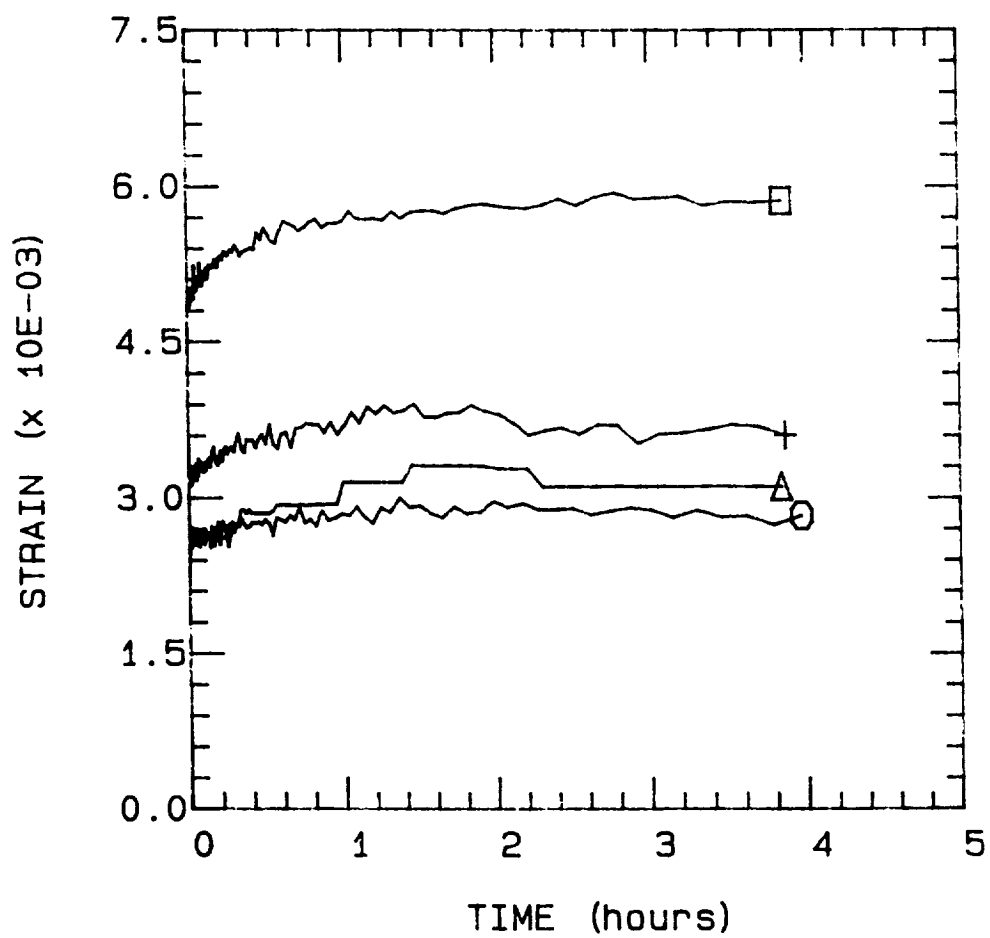
NEXTEL BN480 500 DEG C



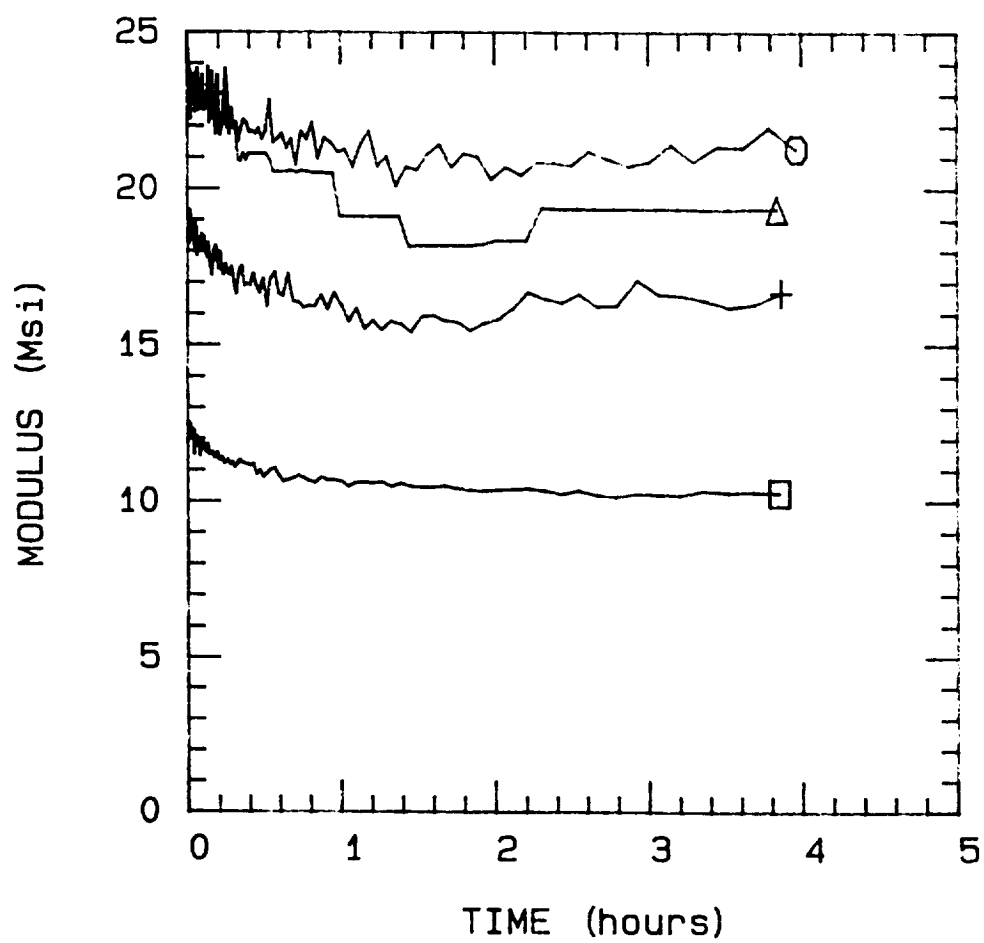
NEXTEL BN480 500 DEG C



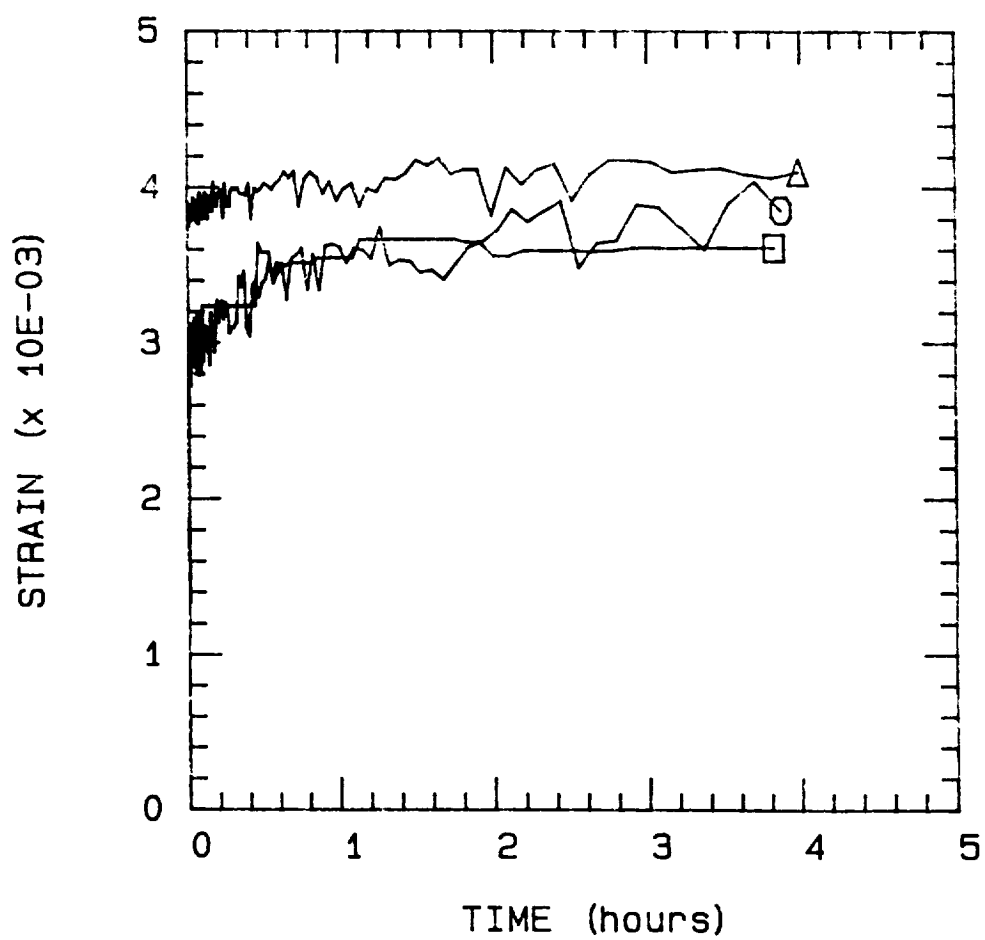
NEXTEL BN480 600 DEG C



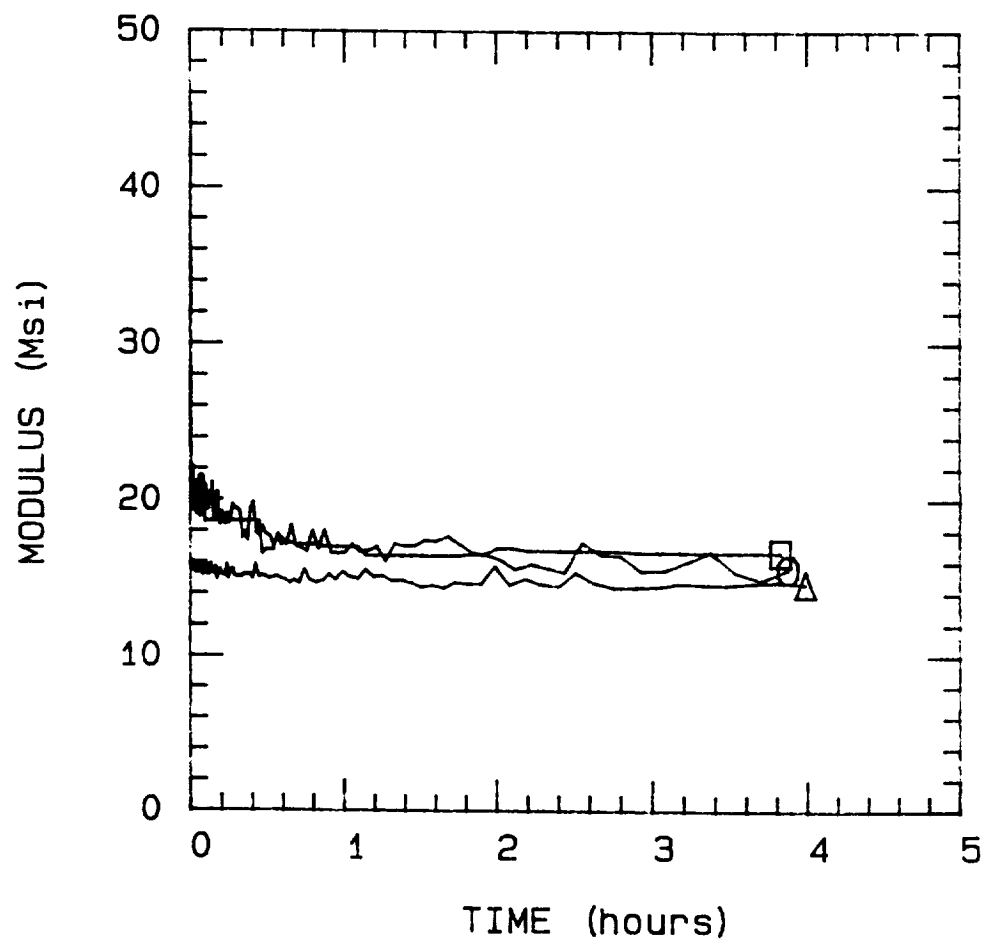
NEXTEL BN480 600 DEG C



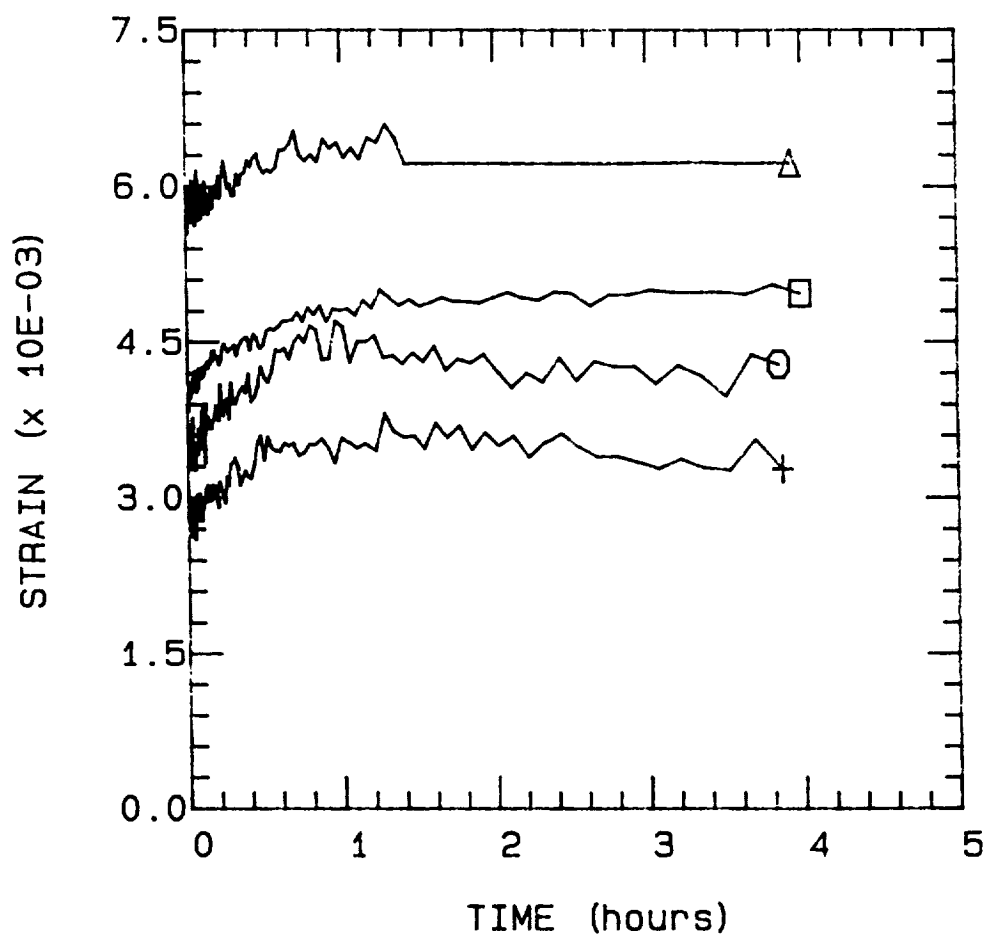
NEXTEL BN480 700 DEG C



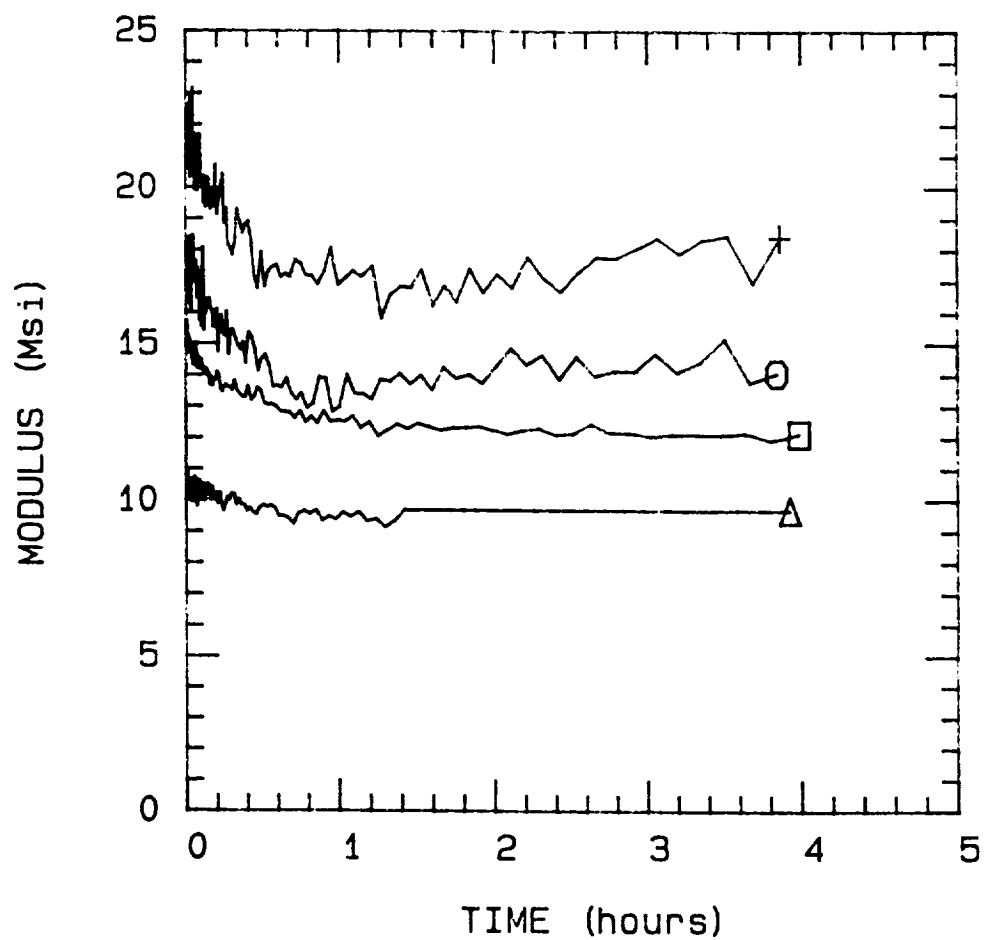
NEXTEL BN480 700 DEG C



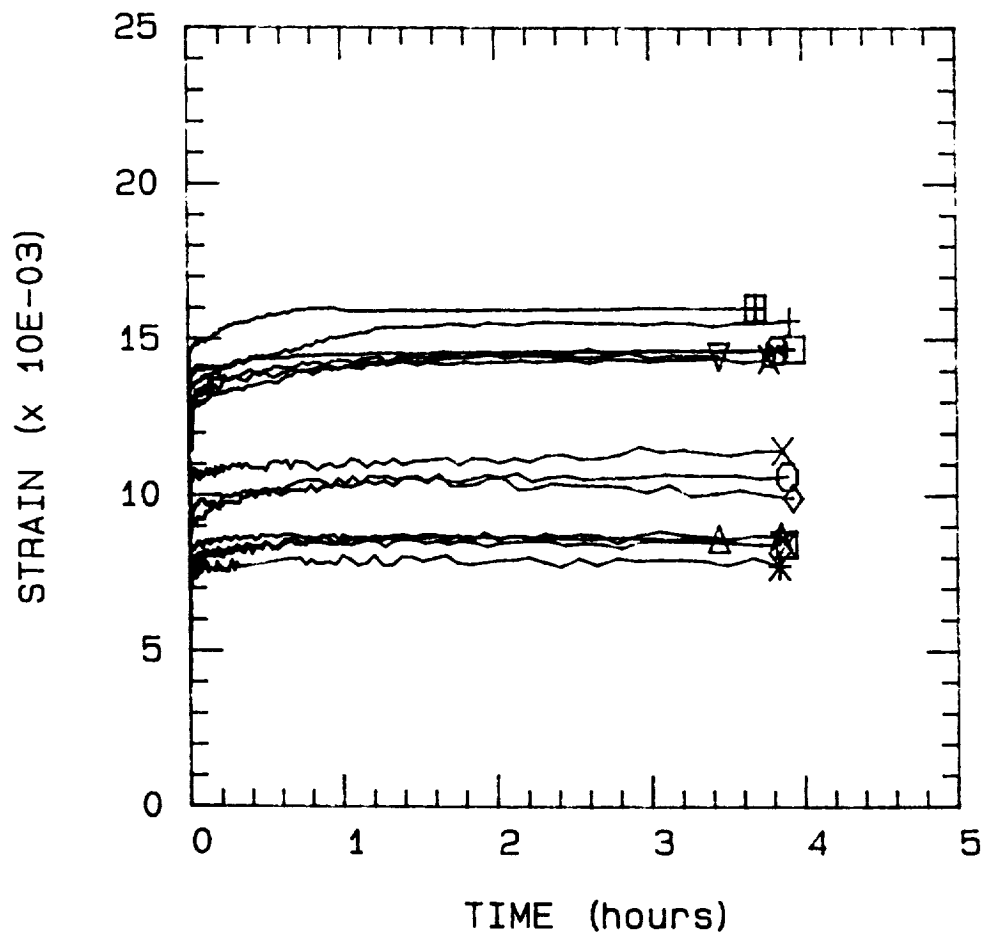
NEXTEL BN480 800 DEG C



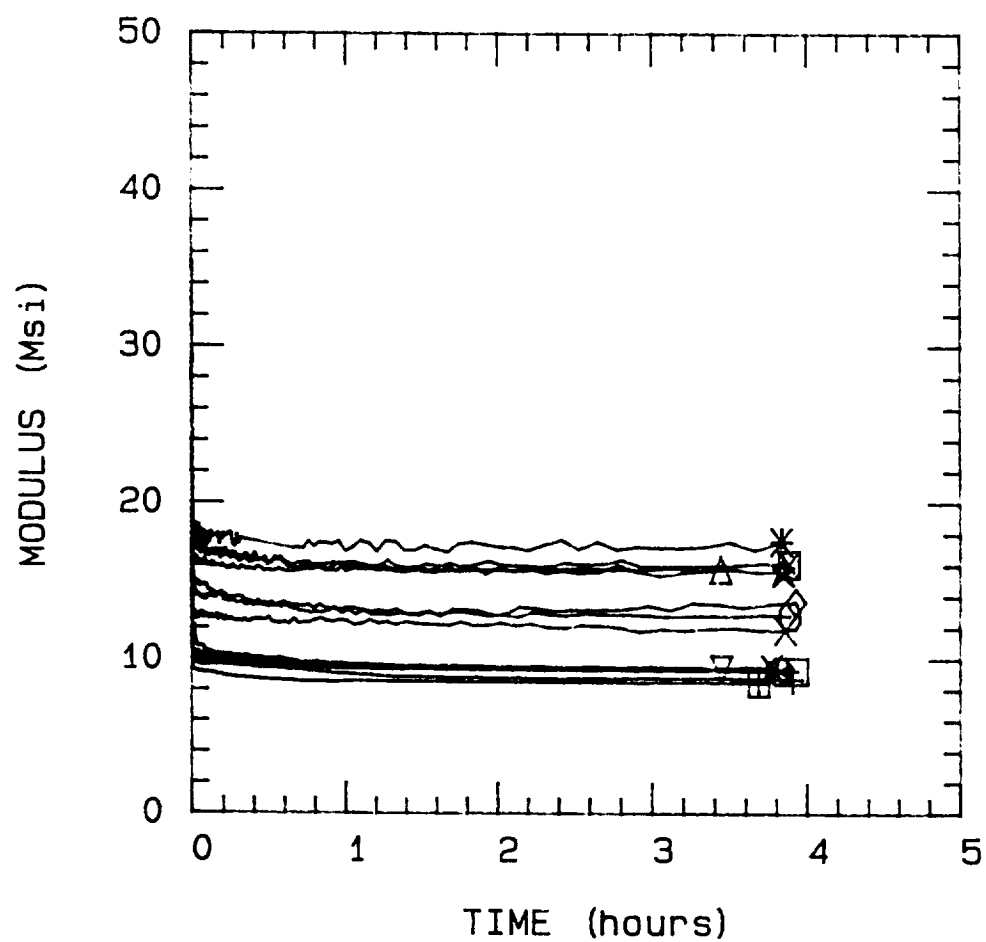
NEXTEL BN480 800 DEG C



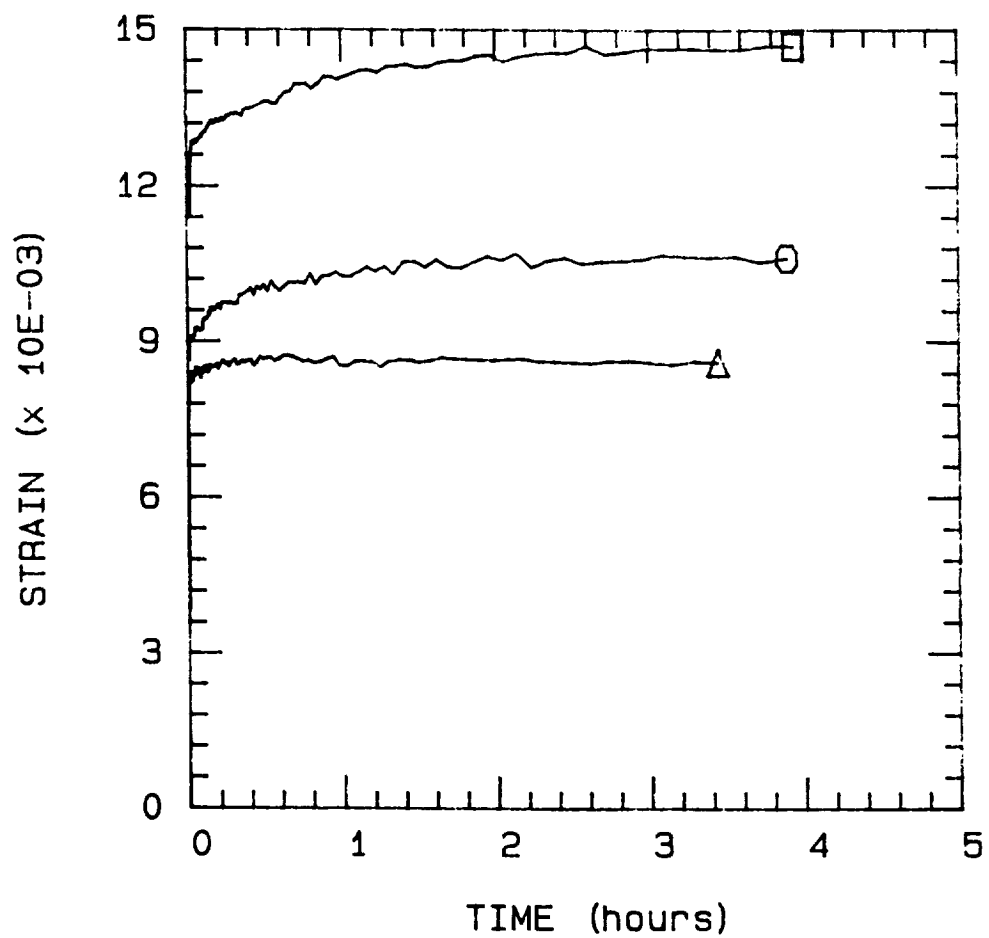
NICALON BNNLM102



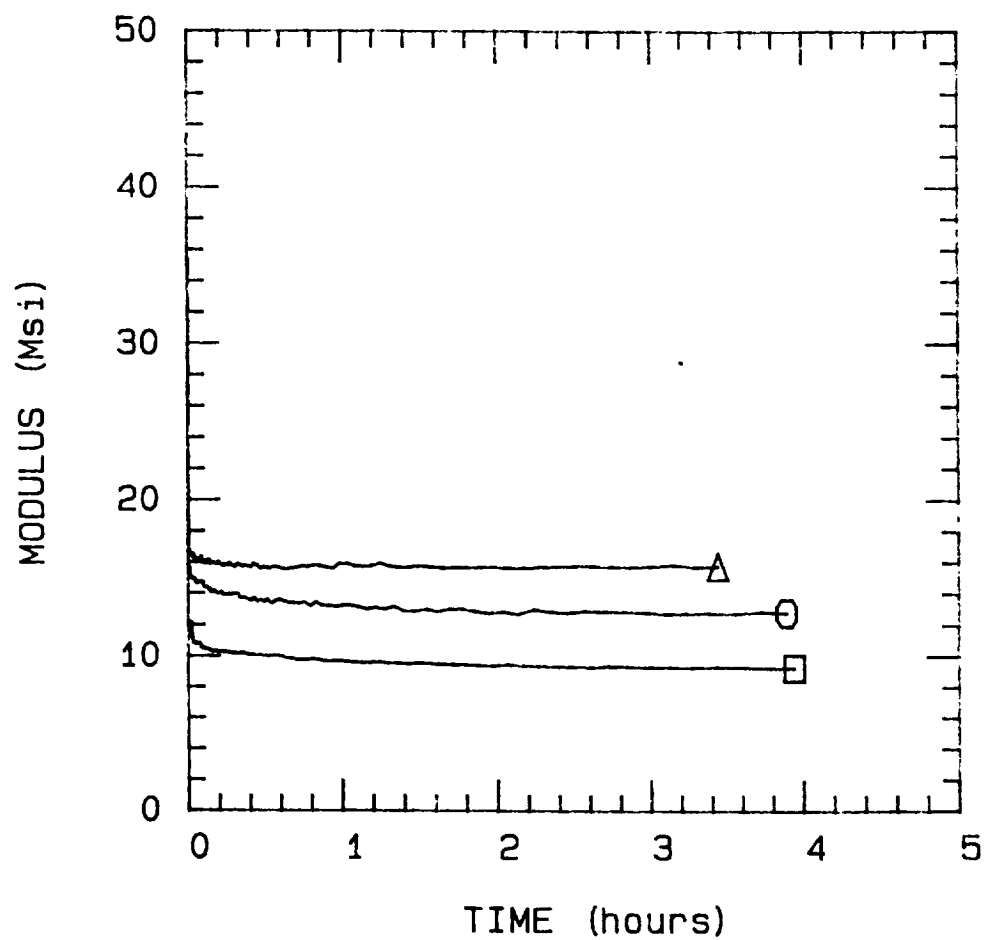
NICALON BNNLM102



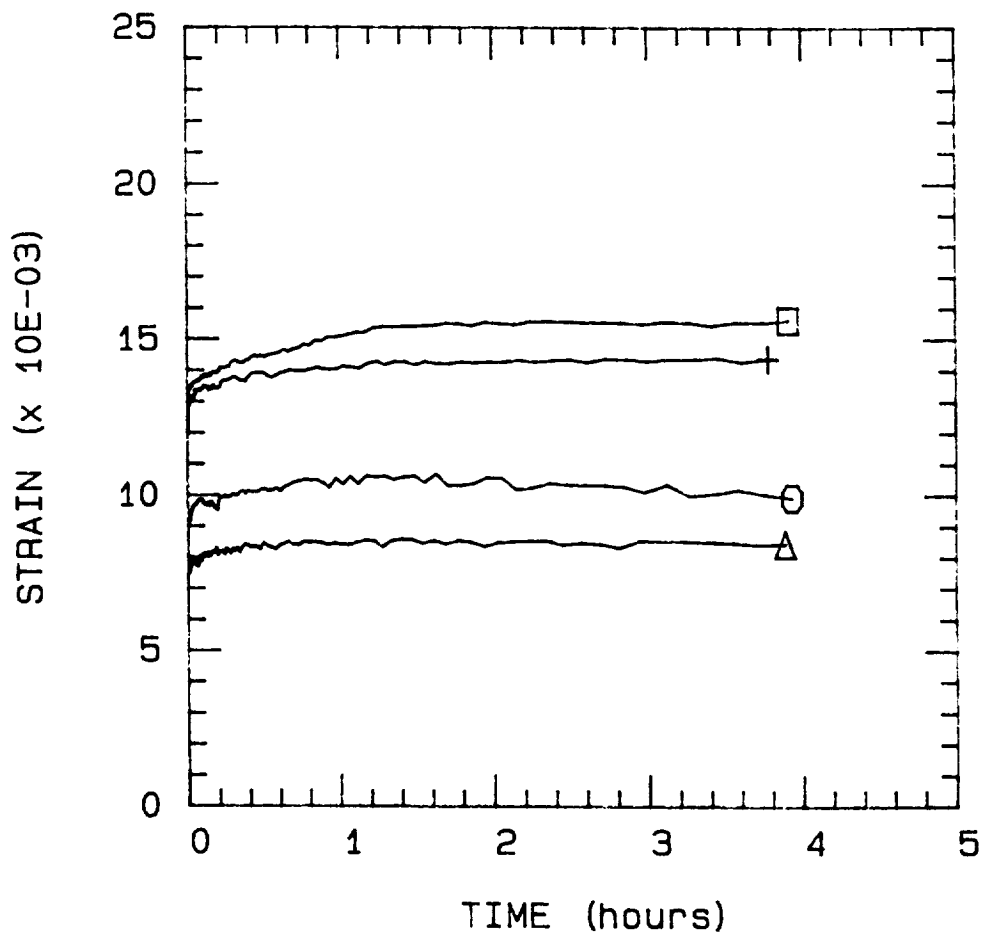
NICALON BNNLM102 500 DEG C



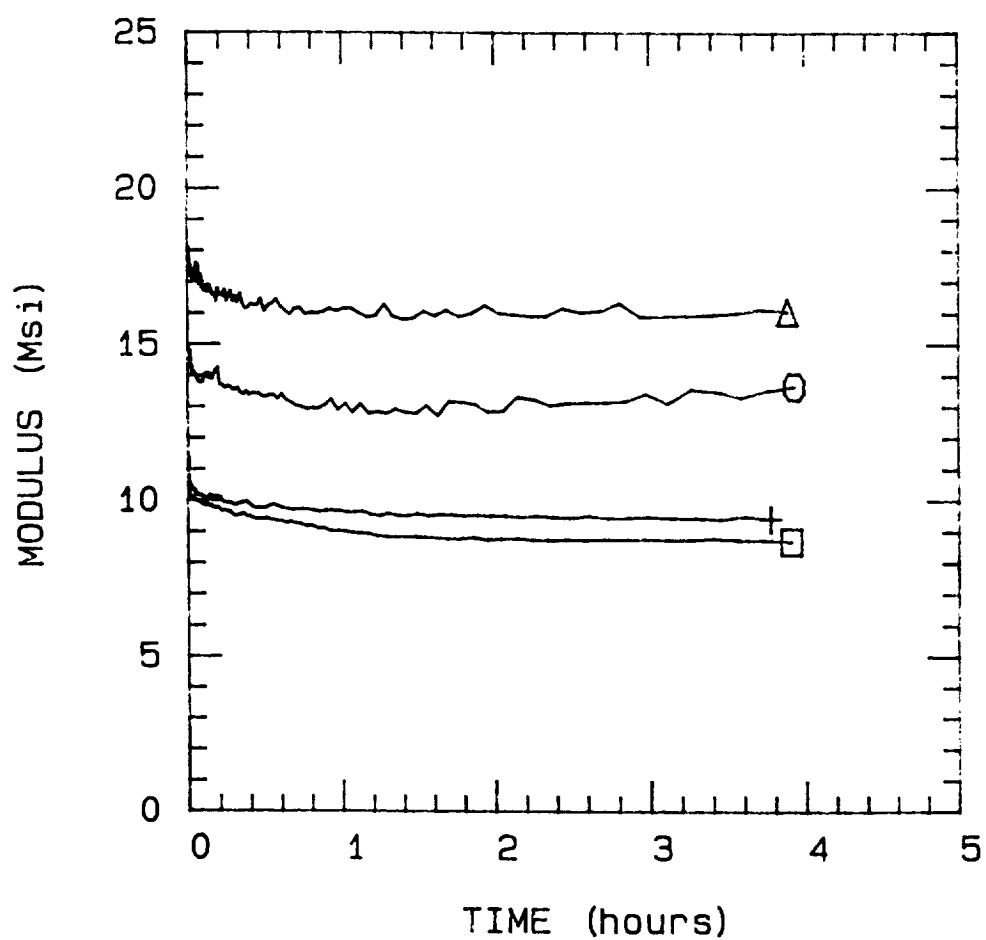
NICALON BNNLM102 500 DEG C



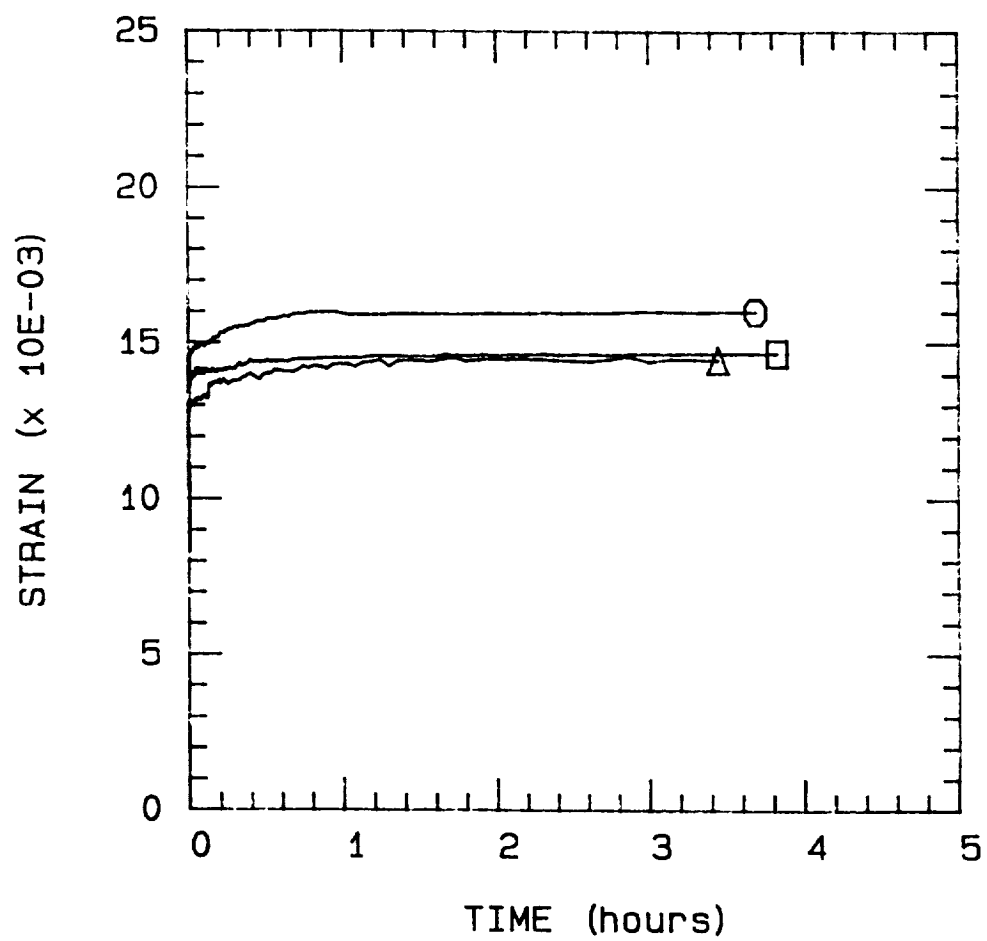
NICALON BNNLM102 600 DEG C



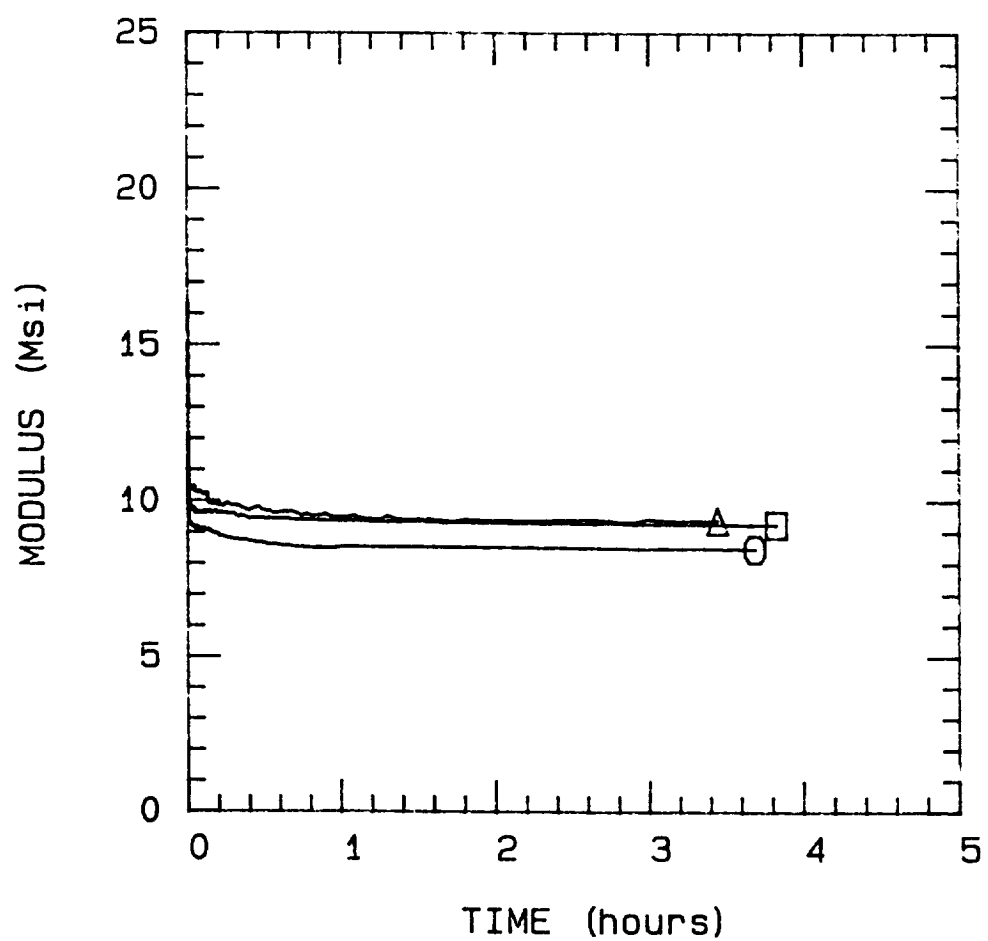
NICALON BNNLM102 600 DEG C



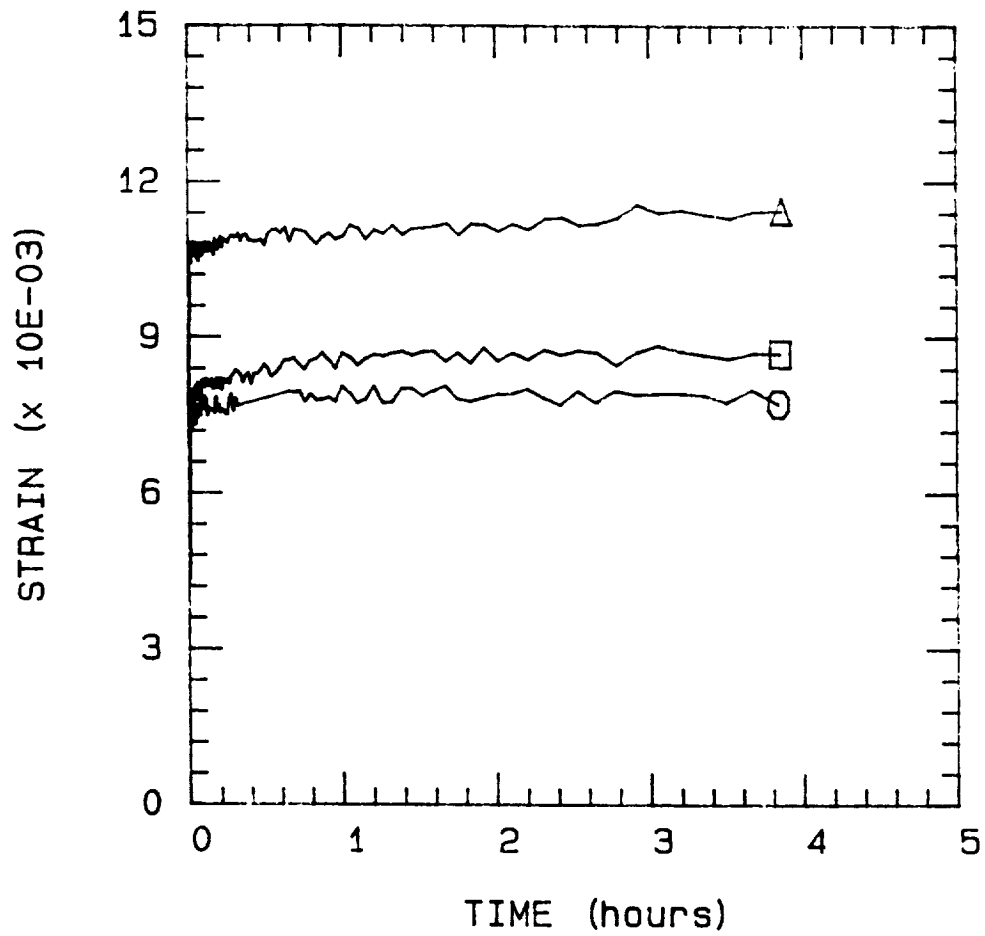
NICALON BNNLM102 700 DEG C



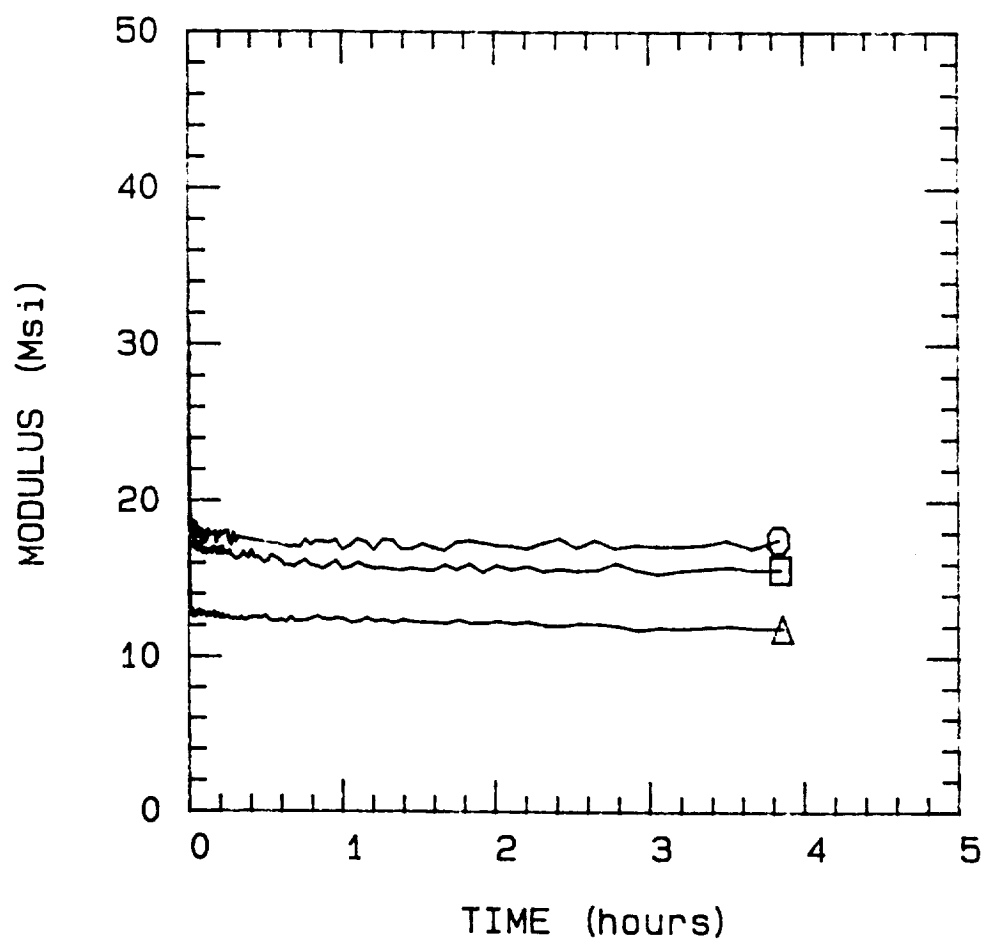
NICALON BNNLM102 700 DEG C



NICALON BNNLM102 800 DEG C



NICALON BNNLM102 800 DEG C





Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Static Tensile and Tensile Creep Testing of Four Boron Nitride Coated Ceramic Fibers at Elevated Temperatures		5. Report Date August 1989	
		6. Performing Organization Code	
7. Author(s) Scott L. Coguill Donald F. Adams Richard S. Zimmerman		8. Performing Organization Report No.	
		10. Work Unit No.	
9. Performing Organization Name and Address Composite Materials Research Group University of Wyoming Laramie, Wyoming 82071		11. Contract or Grant No. NAG-2-470	
		13. Type of Report and Period Covered Contractor Report	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code	
15. Supplementary Notes Point of Contact: D. Kourtides, MS 234-1, Ames Research Center, Moffett Field, CA 94035, (415) 694-4784 or FTS 464-4784			
16. Abstract <p>Six types of uncoated ceramic fibers, viz., J. P. Stevens Co. Astroquartz 9288 glass, Nippon Carbon, Ltd. (Dow Chemical) Nicalon NLM-102 silicon carbide, and 3M Company Nextel 312, Nextel 380, Nextel 440 and Nextel 480 alumina/silica/boria, were static tensile and tensile creep tested at various elevated temperatures. Boron nitride coated Nicalon NLM-102 and Nextel 312, 440 and 480 fibers were also tested.</p> <p>Room temperature static tensile tests were initially performed on all fibers, at gage lengths of 1", 2", and 4", to determine the magnitude of end effects from the gripping system used. Tests at one elevated temperature, at gage lengths of 8" and 10", were also conducted, to determine end effects at elevated temperatures.</p> <p>Fiber cross-sectional shapes and areas were determined using scanning electron microscopy.</p> <p>Creep testing was typically performed for four hours, in an air atmosphere.</p>			
17. Key Words (Suggested by Author(s)) ceramic fibers high temperature testing static tension tensile creep		18. Distribution Statement Subject category: 24	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 130	22. Price

